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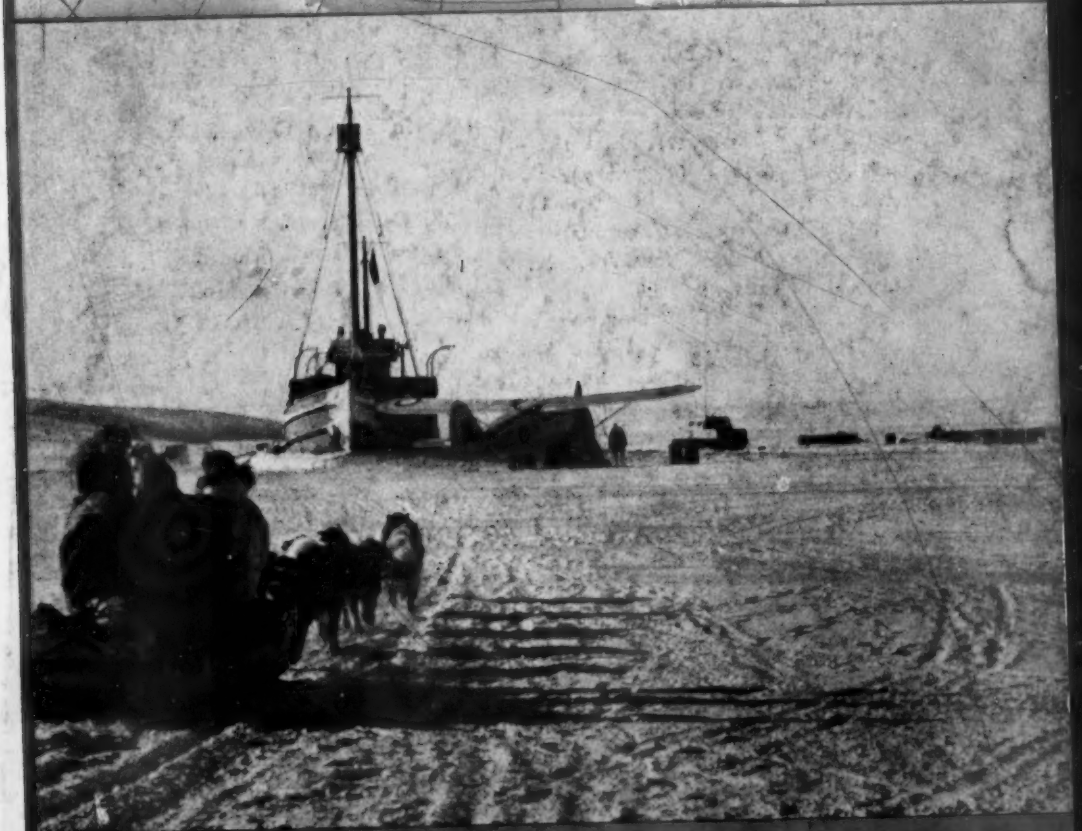

JOURNAL OF THE ARCTIC INSTITUTE OF NORTH AMERICA

THE ARCTIC INSTITUTE OF NORTH AMERICA

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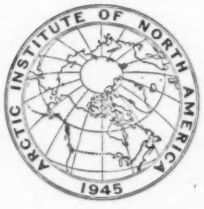
ARCTIC RESEARCH

THE CURRENT STATUS OF RESEARCH AND SOME IMMEDIATE PROBLEMS IN THE NORTH AMERICAN ARCTIC AND SUBARCTIC

ISSUED AS **ARCTIC**, VOLUME 7, NUMBERS 3 AND 4
(To be reprinted as Special Publication No. 2)

Edited by
DIANA ROWLEY



Published by
THE ARCTIC INSTITUTE OF NORTH AMERICA
DECEMBER 1955

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Photo: Canadian Army

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Folding map

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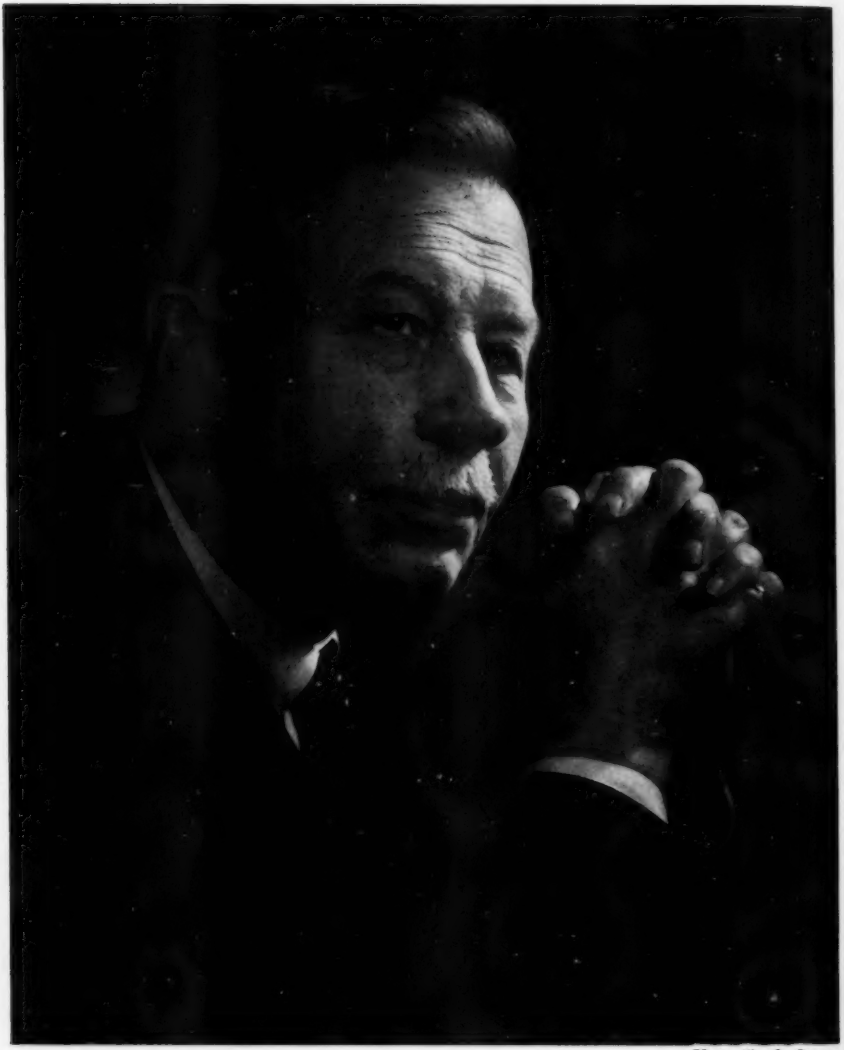

Photo: Karsh, Ottawa

R. C. Wallace, Executive Director, Arctic Institute of North America, from November 1951 to January 1955.

INTRODUCTION

R. C. Wallace*

THE Arctic Institute of North America is concerned with the prosecution of research in the arctic and subarctic regions of the North American continent and in Greenland. The United States, Canada, and Greenland are represented on its Board of Governors. In the ten years during which the Institute has functioned, it has financed, or helped to finance, 177 projects of research in these northern areas, in a great variety of fields of scientific endeavour. In so doing, it has assisted in building up a corps of younger scientists competent to work in arctic territory. From these younger men much will be expected in the future. For the need is great.

There are other agencies that are responsible for research work in the far north—governmental departments, private corporations, industrial firms. But the Arctic Institute of North America is the only agency that is international in scope. It deals with the problems in their wider scientific importance, unimpeded by national boundaries. Not only is this in the best interests of science; it is also in the best interests of international cooperation. There are common problems of defence in which this northern territory plays a very significant part. Because of this fact, a part of the research work in the Arctic in recent years is on the classified list, and does not appear in the current publications. It is none the less of great importance both from the scientific standpoint and in the national interest.

The Research Committee of the Arctic Institute felt that a review of the present status of arctic research in the various fields of science would now be of value both to the scientific worker and to others who are interested in northern development. It was suggested that there would be great value if the present trends and the future needs were emphasized. The Committee has been fortunate in securing the cooperation of highly competent authorities in the sciences that are represented in this volume. The reader will be impressed with the work that has been accomplished. He will be even more impressed with what yet has to be done. The territory is very large. Much of it is not easily accessible. The season in summer is short. The work is arduous and demands special training. The workers are relatively few. This volume will have served its purpose if it stimulates to more widespread activity in arctic research. What has already been done has added greatly to our knowledge of the Arctic. It has done more; it has made the Arctic more accessible to those who are engaged in the development of its resources, and in the well-being of its people.

*Executive Director, Arctic Institute of North America, from November 1951 until his death in January 1955.

The Arctic Institute of North America has already played no inconsiderable part in the encouragement of arctic research. Governmental departments, corporations, and private individuals have assisted the Institute greatly in their work. It is a great pleasure to take this opportunity to express the appreciation of all who are associated with the Institute for the support which has been given so generously. It is the hope of the Governors that, with still wider support, much can be accomplished that the authors of the papers in this volume feel is so urgently needed to be done.

Dr. Wallace was the moving spirit behind this volume until his death on 30 January 1955. As now completed, it is a tribute to his initiative and leadership.

EDITORIAL NOTE

The papers in this volume have been written during the past three years. Most have been brought up to date, but there are a few which have not been changed since they were completed. No attempt has been made to cover every scientific field in the volume, or to restrict the papers to the same geographical region. The authors were left free to deal with their subjects as they wished, and this has naturally resulted in a wide variety of subject and approach. On behalf of the Board of Governors I would like to express the gratitude of the Institute to all those who have written papers for this volume.

A great many people have given much of their time in advising on the material and providing information for the volume and I wish to thank them for their generous assistance. Special mention must be made of the following: Dr. H. S. Bostock, Mr. T. H. Manning, and Dr. A. E. Porsild, who have studied all the manuscripts; the Deputy Minister of Mines and Technical Surveys, Mr. Marc Boyer, who authorized the preparation of the folding map; Mrs. J. G. H. Halstead, who assisted in the preparation of some of the papers; and Mrs. E. F. Roots, who prepared the index.

DIANA ROWLEY, *Editor*
Ottawa, November 1955.

METEOROLOGICAL ACTIVITIES IN THE CANADIAN ARCTIC

R. W. Rae*

THE establishment of a joint weather station by Canada and the United States on Cape Belknap, on the north coast of Ellesmere Island, in April 1950, marked an important milestone in the progress which is being made in our meteorological knowledge of the arctic regions of North America. This station was named Alert after one of the ships of the Nares expedition of 1875–6, which carried out the earliest exploratory work in this area.

Instrumental meteorological observations had been taken at a few isolated locations in northern Canada over one hundred years ago, for example, at the Hudson's Bay Company's Post at York Factory in 1772 and 1773. Numerous arctic expeditions also provided data, but these were only of limited use in meteorological research because they rarely extended over a period longer than a year for any one location. Moreover, observations at different locations were seldom taken during the same years, so that comparisons were difficult.

The need for permanent weather reporting stations in the Arctic was recognized in the earliest days of the Canadian Meteorological Service, but their establishment was a slow process owing to lack of funds, lack of communications, and the inaccessibility of these regions. Stations were established between 1900 and 1910 along the Mackenzie Valley as far north as Herschel Island. In the late 1920's government radio stations were opened at Aklavik, Coppermine, and other parts of the Northwest Territories, enabling northern observations to be transmitted rapidly to forecast centres in the south. During this period stations were also established by the Marine Radio Section in Hudson Bay and Hudson Strait to provide navigational aids to shipping and to take meteorological observations.

The most important and dramatic expansion of the weather station network in the Canadian Arctic has taken place since 1946. Five permanent weather stations, manned jointly by Canada and the United States, have been established on the Queen Elizabeth Islands, in the extreme north of the Canadian Arctic. In March 1952 a station was set up by the United States Air Force still farther north on the Ice Island T3,[1] and observations were transmitted regularly until May 1954. At that date the ice island, which appeared to be drifting along the same path it had travelled previously—

*Canadian Army Operational Research Establishment, Defence Research Board of Canada (formerly Head of Arctic Section, Meteorological Division).

[1]For an account of our present knowledge of the origin and paths of travel of ice islands, *see* Koenig *et al.* (1952).

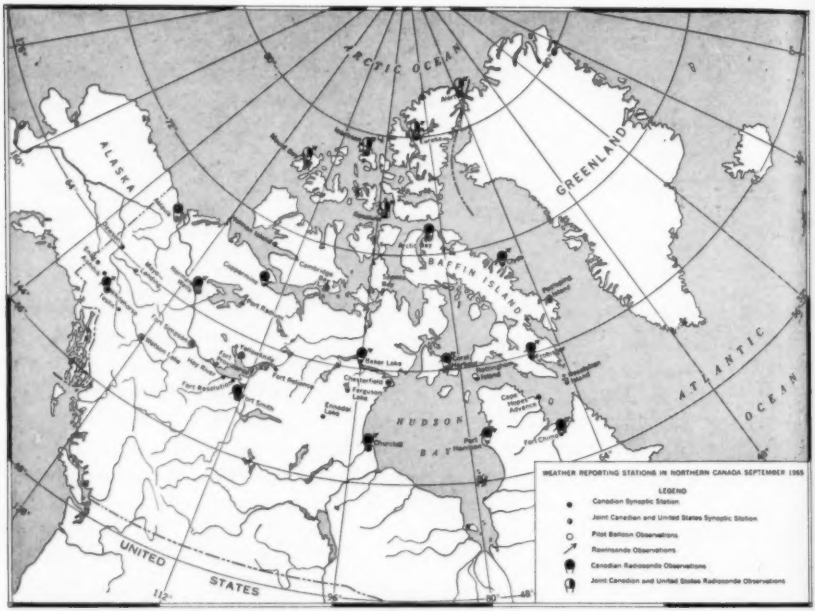

Fig. 1. Weather reporting stations in northern Canada.

clockwise towards the 180th Meridian and then northwards over the pole towards Ellesmere Island—was lying near Alert and was therefore abandoned.[1] It is hoped that these ice islands, which are believed to originate from the Ellesmere Ice Shelf, will make it possible to maintain semi-permanent weather stations in the Polar Basin and to fill a considerable gap in our knowledge.

By September 1955 there were as many as forty-one weather stations operating in the Canadian Arctic and Subarctic between 58°N. and 82°30N. (*see* Table 1 and Fig. 1).

Use of meteorological observations

Meteorological observations are used mainly for three purposes: the preparation of synoptic charts, the compilation of climatological summaries, and physical research. As soon as an arctic station is established, and has made radio contact with a main collecting station such as Resolute, its observations are immediately used in the preparation of synoptic charts at forecast centres throughout the northern hemisphere. Arctic observations have been found to be especially useful in the construction of work charts for long-range forecasting, such as the five-day and thirty-day forecasts that are issued regularly by the U.S. Weather Bureau.

[1] A small United States party reoccupied the ice island in April 1955 on a temporary basis, but meteorological reports were not transmitted. *Ed.*

Table 1. Weather reporting stations in northern Canada, September 1955

Station	*Latitude*	*Longitude*	*Altitude in ft.*	*Types of observations*	*Year first surface obs. made*
Aishihik, Y.T.	61° 39N.	137° 28W.	3170	SH	1943
Aklavik, N.W.T.	68 14	135 00	30	SIPR	1926
Alert, N.W.T.	82 30	62 20	205	SIPR	1950
Arctic Bay, N.W.T.	73 00	85 18	36	SPR	1937
Baker Lake, N.W.T.	64 18	96 05	30	(S)(I)PR	1946
Cambridge Bay, N.W.T.	69 07	105 01	47	S(H)P b)	1928
Cape Hopes Advance, P.Q.	61 05	69 33	240	SI b)	1928
Chesterfield, N.W.T.	63 20	90 43	13	SIP	1921
Churchill, Man.	58 45	94 05	115	SHPR b)	1884
Clyde, N.W.T.	70 27	68 33	26	SPR b)	1942
Coppermine, N.W.T.	67 47	115 15	13	SR	1930
Coral Harbour, N.W.T.	64 11	83 17	193	S(H)PR	1933
Dawson, Y.T.	64 04	139 29	1062	S(H)	1898
Ennadai Lake, N.W.T.	61 08	100 55	1065	SI	1949
Eureka, N.W.T.	80 00	85 56	8	SIPR	1947
Ferguson Lake, N.W.T.	62 52	96 49	400	(H)	1953
Fort Chimo, P.Q.	58 05	68 25	117	SHPR b)	1921
Fort Providence, N.W.T.	61 20	117 40	547	S	1942
Fort Reliance, N.W.T.	62 43	109 06	539	SH	1948
Fort Resolution, N.W.T.	61 10	113 41	549	S(H)b)	1914
Fort Simpson, N.W.T.	61 52	121 21	415	SIP	1897
Fort Smith, N.W.T.	60 01	111 58	665	SHPR	1913
Frobisher, N.W.T.	63 45	68 33	68	SHPR	1942
Hay River, N.W.T.	60 51	115 46	529	SH	1893
Holman Island, N.W.T.	70 30	117 38	30	(S)	1940
Isachsen, N.W.T.	78 47	103 32	83	SIPR	1948
Mayo Landing, Y.T.	63 35	135 51	1625	S(H) b)	1927
Mould Bay, N.W.T.	76 17	119 28	50	SIPR	1948
Norman Wells, N.W.T.	65 18	126 51	240	S(H)PR	1944
Nottingham Island, N.W.T.	63 07	77 56	54	SI	1928
Padloping Island, N.W.T.	67 06	62 21	130	SIP	1941
Port Harrison, P.Q.	58 27	78 08	66	SIPR	1921
Port Radium, N.W.T.	66 05	118 02	600	S(H)	1942
Resolute, N.W.T.	74 43	94 59	209	SIPR	1947
Resolution Island, N.W.T.	61 18	64 53	127	SI	1928
Snag, Y.T.	62 22	140 24	1925	SH	1943
Spence Bay, N.W.T.	69 31	93 27	55	(S)	1951
Teslin, Y.T.	60 10	132 44	2300	SH	1943
Watson Lake, Y.T.	60 07	128 48	2248	SHP	1937
Whitehorse, Y.T.	60 43	135 05	2289	SHPR b)	1904
Yellowknife, N.W.T.	62 28	114 27	682	SHP	1942

Symbols:
- b) Broken record.
- P Pilot balloon or rawinsonde observations.
- R Radiosonde observations.

Surface observations are made and transmitted as follows:
- S At the principal synoptic hours (0030, 0630, 1230, 1830 GMT).
- (S) At some but not all of the principal synoptic hours.
- I At the intermediate synoptic hours (0330, 0930, 1530, 2130 GMT).
- (I) At some but not all of the intermediate synoptic hours.
- H Hourly throughout the 24 hours.
- (H) Hourly during part of the 24 hours, or on request.

Although the density of weather stations in the Arctic has steadily increased in recent years, there are still many gaps at strategic points where the establishment of a weather station would aid materially in the preparation of synoptic charts for the far north. For instance, a station on Melville Island, which has no observation stations within a radius of 250 miles, would help explain such problems as the westward penetration of the moist polar–Atlantic air masses. These air masses, which are much milder than the adjacent arctic air, are sometimes pumped over the Eastern Arctic islands as far west as Resolute by winter storms in the Davis Strait area.

A station on the south coast of Melville Island, in the vicinity of Winter Harbour, was included in the original plans for the network of joint Canadian/United States arctic weather stations, and a cache of prefabricated building components and fuel was made near Bridport Inlet in the summer of 1951. However, because the U.S. Weather Bureau was unable to obtain funds for participating in this project, and because there was insufficient demand for the station to warrant its installation by Canada alone, it was decided in January 1954 to abandon the plan. Nevertheless, a weather station is being established by Canadian agencies on the west coast of Banks Island in the near future.

Climatological records

A minimum of ten to fifteen years of records is necessary for the determination of representative climatic means. Observations from many stations in the Canadian Arctic are clearly inadequate in this respect. Nevertheless, their records have already made it possible to correct climatic charts for this area. For example, temperature observations from Eureka station indicate that the "cold pole" for North America lies in northern Ellesmere Island rather than on the mainland west of Hudson Bay, as previously supposed (Rae, 1951).

The network of stations in the Arctic is too sparse to permit filling in the variations caused by local factors. Some of these variations may be of considerable magnitude, especially in the vicinity of areas like the North Water in Smith Sound, where open water persists throughout the winter. A useful general study of the effect of ice and open water distribution on the winter climate of the Eastern Arctic has been completed by Hare and Montgomery (1949), but the effect of the North Water on the winter temperatures of adjacent land areas requires further investigation.

All the weather stations in the arctic islands are located on the coasts and therefore additional temperature records are needed farther inland. It is likely that temperatures in the interior of the larger islands are somewhat higher in mid-summer, and lower in mid-winter than temperatures near the coast. Some idea of the possible extent of this effect is provided by the records from Pond Inlet, which lies in a sheltered valley, where the average monthly temperatures in winter are about 10 degrees lower than those at Clyde, on the open coast. The occurrence of extremely low winter temperatures in sheltered valleys is especially marked in the Mackenzie basin and the Yukon. For example, the lowest temperature that has been recorded officially in Canada, -81.4°F, occurred at Snag Airport in the Yukon in February 1947.

Upper air observations

In recent years the emphasis in meteorology has been shifting from surface observations to a study of the atmospheric processes at higher levels. A thorough knowledge of upper air conditions in polar regions is essential in order to complete the three-dimensional picture of atmospheric motions over the earth as a whole. Upper air soundings are taken regularly at almost all weather stations in the Canadian Arctic.

An excellent summary of northern Canadian aerological data was prepared by Henry and Armstrong (1949), and now needs to be supplemented with more recent observations from the joint arctic weather stations. Some progress is being made in this regard by the Canadian Meteorological Service with a summary of radiosonde data for all Canadian upper air stations, which will be published shortly.

Observations for air operations

The shortest air routes between North America and many parts of Europe lie across the Canadian Arctic, and several such routes were used to ferry aircraft during the Second World War. Commercial aviation companies are also beginning to take an active interest in the development of transpolar air routes, and both the Scandinavian Airlines System and Canadian Pacific Airlines have commercial flights across the Canadian Arctic on a routine basis. Observations from the arctic weather stations are essential for these operations. The Research Section of the Canadian Meteorological Service is at present analysing and summarizing upper wind data so that frequency distributions of flight times can be obtained for a given route and a given aircraft. The extension of the method to transpolar routes will be possible as soon as sufficient upper wind data are available from the Canadian arctic stations.

Extensive air operations over the Arctic will entail the use of many arctic stations as staging points or alternate landing fields, and will thereby create a demand for terminal forecasts for these stations. Arctic weather forecasting during the summer months does not present insuperable problems to a meteorologist trained in temperate latitudes. In winter, however, when frontal activity in the Arctic is very slight, and the weather is greatly influenced by local factors, an intimate knowledge of the topography and local wind regime is essential in order to determine the frequency of ice fog and blowing snow, which are the two main causes of reduced visibility.

Ice fog studies

Extensive analyses have been made by the Canadian Meteorological Service of the occurrence of low temperature fog at Canadian stations, including those in the Arctic. These analyses have been chiefly climatological in order to determine the physical principles involved.

In general terms, the results obtained so far indicate that the probability of fog decreases as the temperature drops from 32°F to about –20°F. Below –20°F there is a gradual increase in probability, which becomes more rapid as the temperature drops below –30°F. For temperatures below –40°F, ice crystal fog is almost certain to occur, although it may not be of sufficient density to affect air operations. Visibility at the ground is usually greater than one mile in ice crystal fog, but visibility from the air may be limited to the vertical.

Blowing snow

Blowing snow is almost inevitable during arctic winters whenever the surface wind speed is greater than 15 m.p.h. Empirical methods have been

used at many forecast stations to relate visibility in blowing snow to the speed of surface wind. In 1947–9 at Resolute it was noted that for winds below 15 m.p.h. blowing snow was limited to ground drift, and visibility was generally over 6 miles. As the wind increased above 15 m.p.h., more and more snow particles were whirled aloft with a corresponding reduction in visibility, until at speeds over 30 m.p.h. the visibility was less than one-half mile. At moderate wind speeds, the severity of blowing snow for a given wind speed was not constant from day to day. This variation might be explained by the difference in the degree of binding among the crystals forming the snow surface. Further observational data concerning snow surface conditions are required to evaluate the magnitude of this effect.

Research in arctic meteorology

Observations of the various meteorological elements both at the surface and in the upper air are being steadily accumulated from the arctic stations to provide data for research. It is self-evident that before research can be carried out on any problem it is necessary to begin with accurate observations, as any inaccuracies in the basic data will tend to invalidate the results obtained. For this reason a large proportion of arctic meteorological data must be treated with caution, for some meteorological elements cannot be measured accurately in the Arctic. The elements which present the greatest problem are humidity, snowfall, and, in winter, the amount and type of clouds.

There are many organizations in North America carrying out research in arctic meteorology. One such group is the Arctic Forecast Team, Meteorological Division, Department of Transport, at Edmonton, which is working mainly in the synoptic field. Dewar, Thompson, and Wilson, who are members of the team, and Markham, a former member, have published their results in a number of Meteorological Division circulars.[1]

Humidity

The ordinary hair hygrometer becomes inoperative at temperatures lower than about –20°F, and is therefore useless throughout most of the arctic winter. Moreover, the difference between readings taken with wet- and dry-bulb thermometers at low temperatures is generally so small that the observer cannot detect it, and often arbitrarily manipulates the readings to give a difference of 1/10 of a degree. There is no need to elaborate on the worthlessness of such observations, and yet winter humidity observations are published for many arctic stations that are not equipped with any other humidity measuring devices than a hair hygrometer and wet- and dry-bulb thermometers.

A frost-point hygrometer has been developed, which can measure the absolute humidity of very dry air at temperatures as low as –90°C (Brewer *et al.*, 1948), but it is too complicated for routine use at weather stations, and none of the Canadian arctic stations are equipped with it. The Instrument

[1]See references.

Section of the Canadian Meteorological Service is working on the development of a visual type of dew-point apparatus which may also be used at low temperatures. A small thermistor is inserted into the surface of the instrument just below the dew observation button. The deposit on the button is observed through a fixed magnifying glass, and the sampled air is pumped on to the surface through a jet, and cooled by expanding CO_2 from a bottle through another jet just below the button. Rate of cooling may be adjusted by a needle valve which regulates the escape pressure. Extensive tests indicate that the instrument is satisfactory for routine use, and although it is expensive to manufacture, it is hoped that some of the Canadian arctic stations can be supplied with one in the near future.

Snowfall

Measurements of snowfall at arctic stations are often rendered inaccurate by drifting. Other inaccuracies are likely to occur in published figures of arctic precipitation when conversion is made from snow to an equivalent amount of rain. The most widely used conversion factor is ten inches of snow to one inch of rain. This ratio is approximately correct for newly fallen snow in temperate latitudes, but for arctic regions, five inches of snow to one inch of rain would be a closer approximation.

Cloud type and amount

Cloud observations must be made indirectly during the winter dark period when the moon is not up. The presence of clouds is assumed when stars are not visible in any section of the sky, and the height and type can usually only be guessed. Nevertheless, the low-powered ceiling projectors recently installed in some of the arctic stations are proving helpful in increasing the accuracy of observations.

Permafrost studies

Perennially frozen ground underlies the greater part of the Canadian Arctic, and undoubtedly exercises considerable influence on the climate of the region. The Arctic Forecast Team is already carrying out a study of the meteorological aspects of permafrost, but further investigations are needed.

Jet streams

One of the most striking advances to be made in meteorological research in recent years was the discovery of a narrow zone of extremely strong winds in the upper troposphere. This belt of high winds, which has been given the descriptive name of "jet stream", is usually associated with the polar front, but there is evidence to indicate that a jet stream may also be associated with the arctic front at times. For example, Greenaway (1950, p. 3) has made the following observation: "The strongest wind encountered was in February, and had a speed of 118 kts. blowing from the NNE at 12,000 feet about 40 miles off the north coast of Borden Island. At the time light to moderate turbulence was encountered and a layer of cloud extended up to flight level. Wind velocities measured at half-hour intervals on either side of this wind

were not greater than 45 kts. This exceptionally strong wind has many of the characteristics of a jet stream and may be due to similar causes. At the time there was an extensive low over the eastern part of the archipelago, and as far as I can judge from the available data, the arctic front was probably fairly far north. We may have here an indication of a jet stream associated with the arctic front and the absence of previous evidence of this phenomenon may be simply due to the meagre upper air records in high latitudes".

Studies of the structure and behaviour of jet streams at high latitudes are being pursued by the Research Section, Canadian Meteorological Service, by means of cross-sectional analyses of selected situations. In particular, an attempt is being made to determine the relationship, if any, between such jet streams and fronts in the Arctic (McIntyre and Lee, 1954).

Ozone

The basic meteorological observations consist of temperature, pressure, humidity, and wind. The radiosonde and rawinsonde are the main tools of synoptic meteorologists for determining these properties from the surface to high levels. However, more and more attention is being focused by research meteorologists on other types of observations, which may throw additional light on meteorological problems.

Ultraviolet radiation from the sun in the wave length band 2,200 to 2,900 A is absorbed in the upper stratosphere. It has been demonstrated that the absorbing agent is ozone, and its total amount above a station may be measured by means of an instrument known as a Dobson spectro-photometer. Changes which occur in the ozone spectrum provide information about the height of the centre of gravity of the ozone layer and also the nature of the vertical distribution curve.

Although there are day to day variations in the amount of ozone above any station, the average amount has been observed to increase with latitude from a minimum at the equator to a maximum at high latitudes. According to Craig (1950, p. 10), the ozone maximum occurs at a latitude between 45° and 60°N., with a gradual decrease farther poleward, except perhaps in the spring. However, very few observations have been made north of latitude 70°, and observations from a place such as Alert, near latitude 82°30N., would provide valuable material for further study.

The importance to meteorology of research on atmospheric ozone results from the fact that the ozone content of the air appears to be relatively stable, and that day to day variations in the amount of ozone in any one place are caused largely by advection or turbulence. For this reason, ozone observations may provide a means of studying air circulation at high levels, and aid in completing the picture of the general circulation of the atmosphere.

At present there is only one Dobson spectro-photometer in Canada, and it is located at Edmonton. An instrument at one of the weather stations in the Archipelago would assist materially in exploring the potentialities of routine ozone observations in weather forecasting, and be of great value in high latitude observations.

Radiation measurements

In arctic regions the annual outgoing radiation is greater than the incoming radiation, whereas in tropical regions the reverse is true. Since there is no evidence to indicate that the Arctic is getting progressively colder and the Tropics progressively warmer, there must be some mechanism which provides for the exchange of heat between the Arctic and the Tropics. If the net radiation loss in the Arctic and the net gain in the Tropics were accurately known, a computation could be made of the magnitude of air transport required between the Arctic and the Tropics to maintain equilibrium conditions.

Very few radiation observations have been made in the Canadian arctic islands, though some solar radiation measurements are being made at Resolute. Moreover, measurements of the temperature profile in the lower layers of the air at Alert, and soil temperatures at Resolute, provide additional material for radiation studies. It is hoped to extend the scope of the present radiation measurements by installing a long-wave radiometer at Resolute in the near future.

Studies on the relationship of solar radiation, visibility, sunshine duration, and vertical distribution of humidity are being made by the Canadian Meteorological Service in order to be able to predict the daily amount of insolation at any specific location, and to prepare charts of monthly mean solar radiation, as well as mean clear-day radiation amounts, for all Canada. Theoretical studies of long-wave radiation are also being carried out, which will eventually be applied to determine fluxes and cooling rates, and to interpret radiation measurements in the Arctic.

Night sky radiation and aurorae

The general structure of the upper regions of the atmosphere has been surmised from many different types of observations such as meteors, night sky radiation, and aurorae. Experiments have been carried out in several countries on the measurement of night sky radiation (Hulburt, 1951). Observations have been taken as far north as 63°, and from the data, it was concluded that on nights when aurorae were not present, the brightness of the sky did not vary because of changes in latitude. It would be of interest to carry out a series of observations during the polar night at a station as far north as Alert, to determine whether these results apply to the arctic regions as well.

Detailed auroral investigations have been made in Norway, but such investigations in the Canadian Arctic would be of special interest owing to the proximity of the north magnetic pole. A limited series of auroral observations was begun for the Radio Physics Laboratory of the Defence Research Board at Alert, Eureka, Isachsen, and Mould Bay, in the fall of 1952.

Canadian responsibility in arctic meteorology

In view of the extent of the Canadian sector of the Arctic, Canada shoulders a heavy burden of responsibility for the maintenance of weather stations in the Arctic. This responsibility has been accepted, although the

expense of establishing and maintaining stations in isolated arctic locations is vastly greater than in more settled areas. The joint program being carried out by Canada and the United States in the arctic islands is a splendid example of international cooperation. It is providing a means for obtaining extensive meteorological and other scientific data, which will be available for research at centres throughout the world.

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RESEARCH IN GEOLOGY AND GEOMORPHOLOGY IN THE NORTH AMERICAN ARCTIC AND SUBARCTIC

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THIS paper defines, in general terms, the status of research in the north in geology and geomorphology, and reveals some of the limitations to present knowledge in these fields.

The authors are grateful to those who have assisted them. Thanks are due particularly to Y. O. Fortier, J. M. Harrison, and C. S. Lord of the Geological Survey of Canada, and to George O. Gates, George Gryc, Troy L. Péwé, Clyde Wahrhaftig of the U.S. Geological Survey, and to Thomas G. Payne formerly of the U.S. Geological Survey.

Geological mapping

Of first importance in the understanding of the geology of any region is the availability of adequate geological maps. Ideally such an understanding develops from the exploratory, through the reconnaissance, to the detailed stage. In the North American Arctic and Subarctic this pattern broadly applies, but the six great regions, Alaska, Yukon, Mackenzie, Keewatin, Ungava and Franklin each present special problems owing to their diversity in character. Because of this it is not feasible to adhere everywhere to the ideal pattern, and individual variations are necessary to facilitate more rapid coverage with maps of practical scales and standards for the different terrains.

In Alaska, the Yukon, and the Cordilleran parts of Mackenzie, the system is fairly standard. Exploratory, reconnaissance, and detailed mapping are in progress, though at different stages of completion. The exploratory geological mapping, usually published on a scale of about 1:500,000 or smaller, is perhaps 60 per cent complete in Alaska and in the Yukon. It is followed by reconnaissance mapping using scales of about 1:250,000, and for this some 38 per cent of Alaska and 15 per cent of the Yukon have been covered. More detailed maps on scales from 1:63,360 to 1:12,000, and occasionally on even larger scales, are made of selected areas.

In the unforested parts of the Precambrian areas of Mackenzie and Keewatin geological mapping is following a somewhat different course. In 1952 "Operation Keewatin", undertaken by C. S. Lord and others of the Geological

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Survey of Canada, introduced a new method of Canadian reconnaissance mapping. By use of helicopters and supply aircraft 57,000 square miles were methodically traversed for geological maps on a scale of 1:500,000 and, where it seemed desirable, interesting localities were examined in greater detail. This method of mapping is being applied to all suitable terrain where it is filling the role of both exploratory and reconnaissance mapping of bedrock and Pleistocene features. From its results areas for more detailed mapping will be selected. In the forested areas of these districts, largely in Mackenzie where the aerial technique is less suitable or impracticable, the system of mapping is similar to that used in Alaska and the Yukon; and some 16 per cent of these areas have been completed on a reconnaissance scale of 1:250,000.

In Ungava, which is largely forested, the exploratory mapping has been taken over by companies holding great concessions, and the government work has concentrated on reconnaissance mapping. The Labrador Trough region is being covered first, and about 10 per cent of Ungava has been mapped on a scale of 1:250,000 and more detailed mapping of selected districts is also in progress.

For Franklin, the plan is similar to that for the open areas of Mackenzie and Keewatin and coverage with maps on a scale of 1:500,000 is the first objective. The work was first begun with boats for transport in the field, but in 1955 "Operation Franklin" was carried out almost entirely with helicopters and supply aircraft over a huge area in the Queen Elizabeth Islands. No mapping on the reconnaissance scales is planned, but detailed maps of selected areas are contemplated.

Most of the geological mapping in the north has been of bedrock. In the past few years, however, some minor attention has been paid to the mapping of surface deposits, and the need for such mapping must be emphasized in view of the development that is underway or planned in the north.

In the last ten or twelve years, mapping programs have been accelerated by the development of modern methods, instruments, equipment, and transportation, and by the increase of general interest in the north. Among the new "tools", the use of air photographs is of paramount importance, and has done more than any other development to enhance the speed, accuracy, and completeness of mapping on all scales.

In general, while geological mapping in the Arctic and Subarctic, and the compilation and release of information have been and will probably continue to be the responsibility of government surveys, certain work is nevertheless suitable for other groups. In particular, the fields of local studies and mapping, and of research on topical problem studies, which always includes some mapping, may be mentioned. Some notable contributions to geological mapping have already been made by companies, and various agencies in papers, periodicals, books, and maps. But as a rule, companies have no desire to make their work public, although a few in Canada have turned over their general results to the government for publication. A notable instance is the 'Canol geological investigations', largely the work of the Imperial Oil Company Limited, compiled by G. S. Hume and T. A. Link, and published in Paper

45-16 of the Geological Survey of Canada. The recent condition for grants of large prospecting concessions in Canada, that copies of the geological maps and reports of the companies be given to the government within a specified period is expediting mapping by non-governmental groups.

Geological processes

Like geological mapping, the study and interpretation of geological processes peculiar to, or of special importance, in the north offers a most fruitful and much neglected opportunity. It should, of course, be kept in mind that processes such as ore deposition and vulcanism can be studied more effectively in temperate and accessible regions, although there will always be special instances when research on these two processes will have to be carried on in the north.

Under the rigorous climate of the Arctic and Subarctic, both chemical deterioration and mechanical disintegration differ from these processes in more temperate areas. This difference is due in part to frequent temperature changes, which cause materials near the surface to move back and forth from below to above the freezing point of water. The transportation of released material has not yet been investigated in the systematic fashion it deserves. More thorough studies should be made, for example, of the effects of rapid fluctuation and frequent overloading of glacial streams, the sediment contributed by the abrasive action of glaciers, and the transportation of material by floating ice on rivers as well as on the sea, the drying of surface materials in relatively arid areas as a result of the lowering of the permafrost level, the rapid growth of plants that form the mat-like tundra vegetation in the long, warm, summer days, severe and repeated frost action, low evaporation, and many other factors. Frost action is one of the most important geological processes in cold areas; some work has been done in the laboratory, but quantitative study in the field is needed.

Of special importance in the north is the mass wasting of material through such means as solifluction and rock glaciers. Some qualitative investigations have been made in these fields but there is specific need now for quantitative data, for example on rate of movement and angle of slope. The rate and type of soil formation would also be significant. Data could be gathered from carefully selected, easily accessible localities without great cost. As might be expected, the deposition of material is also widely different from the better known pattern in lower latitudes. This difference obtains on land and in streams, lakes, and the Arctic Ocean.

Large annual icefields are developed along many of the major rivers of the Arctic. The ice of such fields is sometimes referred to as "aufeis", and the process as "glacial icing". The literature is not clear as to just how such icefields form, how they grow, or the nature of their annual cycle. Some of these fields are large, 50 square miles or more, and their study would combine the application of geomorphology, hydrology, and related subjects.

Permafrost

A better understanding of the various phenomena of permafrost would be immediately useful in construction and development projects in the north. The English-speaking countries have made a late start in systematic investigations of permafrost, although considerable opportunity is available in North America to study geological processes controlled or modified by permafrost. Some work has been done in the investigation of such processes. For instance, R. E. Wallace and R. F. Black in Alaska have studied lake modification. Physiographic phases of the floodplain have been studied in permafrost areas, and the processes controlling them have been worked out by T. L. Péwé on the lower Yukon River, and the results applied to other large rivers in interior Alaska such as the Kuskokwim, Koyukuk, and Tanana. Processes important in the development of thermokarst topography have also been partially studied, and ice wedges have been examined in some detail. Accurate temperature measurements of frozen ground, including long- and short-term fluctuations, are now being made, and have been discussed by G. R. MacCarthy and M. C. Brewer. The origin of permafrost, however, has scarcely been touched upon.

Glaciology

In general, glaciation and glaciology in North America can be studied most effectively in the Subarctic ranging into the temperate zone but some work in the Arctic is essential. Substantial progress and much interest in these large fields have recently been shown by a number of groups, especially in Alaska and the Yukon, but much more remains to be done. In particular, research is needed on the glaciers and icefields of the north and on all the circumstances of their existence throughout postglacial time, before a proper grasp can be obtained of the many variable factors which lead to the presence of glaciers and to the phenomena associated with Pleistocene glaciation. In conjunction with these studies, work on glacial processes, including the physics of ice, is needed. A complete plot of all the northern glaciers, including the present boundaries and past stages, and extending back as far as possible in geological time, would also be valuable.

The Arctic and Subarctic of North America contain excellent fields for glaciological research in the western Cordillera and the eastern and northeastern islands. On the west there are the numerous great valley glaciers of the Alaska Range, the various coastal ranges, and the St. Elias Mountains. The larger glaciers, which have their sources in the icefields of these great ranges, flow outward in nearly all directions to regions of very different climates. Those moving southward are subjected to the relatively even temperatures and nourishing high precipitations of the coast in contrast to those passing northward into the semi-arid interior climate with its extreme temperatures. In these ranges, too, every variety of alpine glacier from the small, isolated individuals in cirques to great branching, many-headed, valley glaciers exist. It seems likely that the study of the distribution of the small glaciers and

groups of glaciers in northern Alaska, the Yukon, and western Mackenzie may shed light on the local microclimates, recent climatic changes, and geological history. The recent development of these regions, with the accompanying improvements in transportation, has brought a number of glaciers within the reach of modestly financed expeditions, of which many will be required in the future, since each glacier commonly requires individual study.

Northeast of the Mackenzie Mountains, the nearest glaciers and icefields are those of the eastern and northeastern Arctic Archipelago, where they are scattered over the areas east and north of an arc extending from Meighen Island, through Devon Island, to Cumberland Peninsula on Baffin Island. These glaciers, lying largely in latitudes well north of those on the western mainland of the continent, have environments of their own, and some appear to be thriving in areas which, in the light of present knowledge, receive inadequate precipitation for their existence.

In Alaska, the study of glacial processes has been receiving increasing attention. The early reconnaissance work done by Capps, Moffit, Smith, and others who studied glacial deposits incidentally to bedrock geology, has given way to a new phase in which the glacial deposits of broad areas have been mapped by Detterman, Fernald, Hopkins, Karlstrom, Krinsley, Muller, Péwé, Wahrhaftig, and others, and the information has been brought together by Péwé for publication. A glacial map of Alaska comparable in quality to the 'Glacial map of the United States', is now being compiled, by tying together by means of airphoto interpretation the areas where study has been completed.

In the Canadian north the study of Pleistocene and glaciological phenomena is increasing. This trend is due partly to the growing realization of the economic importance of the region, and also to the fact that the new topographical maps and air photographs are making information expressed by surface features more readily obtainable for large and remote areas. In the Yukon, much attention is being paid to the study and mapping of overburden, glacial phenomena, and general surface features both in the glaciated and unglaciated regions, but this work is still second to the mapping of the bedrock geology. In the other districts to the northeast the same is true. In 1952 the Geological Survey of Canada allotted a specialist to "Operation Keewatin", to devote his entire time to Pleistocene and surface geology, and this practice is expected to be continued for similar operations in the future.

Some problems of soil formation in different parts of the Arctic and Subarctic are closely associated with glaciation. Great differences, for instance, are apparent between the well developed soils of the large Yukon valleys between 60° and 65°N. latitude and the general lack of soil in central Ungava at about 55°N. The study of the factors contributing to this difference may show that the two regions have had different climatic histories since the close of the Pleistocene epoch.

The investigation of the origin and movement of loess provides a great opportunity for studying processes related to glaciation. Alaska, particularly, and the southwestern Yukon, with their active, braided, glacial streams and outwash plains, offer excellent fields for such studies.

Stratigraphy and structure

The geology of an area cannot be fully interpreted or correlated with that of other areas without understanding the geological succession in the stratified rocks, their structure, and their relationships within the area and with other areas. Over much of the North American Arctic, knowledge of the stratigraphy and structure is fragmentary, general, and only broadly useful.

The nature of the major geological structures in Alaska is fairly well known, and many details of the structural geology of a few areas, such as much of the Arctic Slope, have been studied. Over most of Alaska, however, structural detail has not been worked out. Such details are needed both for local application, and for helping to fill the gaps in current knowledge of the major structural patterns. Modern air photographs of Alaska are expected in the near future to lead to major advances in understanding the structural geology of the Territory.

Regional studies by specialized stratigraphers and paleontologists are particularly needed. The value of such work can readily be seen in the recent and very important contribution to knowledge of the Jurassic and Cretaceous systems in Alaska made by Ralph Imlay of the U.S. Geological Survey. One particularly important part of Alaska requiring study is the area along the international boundary between the Yukon River and the arctic coast. This, and studies of some other areas, might well extend across national boundaries, and include reviews of Siberian literature.

Detailed paleobotanical collecting and research, including spore studies, are needed to solve some Cretaceous and Tertiary problems in Alaska. For example, gently deformed Tertiary sections containing coals of low rank, as in the Kenai and Little Susitna districts, have in the past been assumed to be equivalent to more strongly deformed Tertiary sections containing high-rank coal beds, as in the Matanuska Valley area. It is now believed that the latter rocks, which are approximately conformable with Cretaceous strata, are older, possibly Paleocene, and may unconformably underlie the large areas of the less deformed beds, which in turn may be Eocene. The solution of this problem by paleobotanical studies, supplemented by test drilling, is important because of the shortage of bituminous coal in Alaska.

Detailed micropaleontological studies of Mesozoic formations in Alaska are also needed. Mesozoic rocks generally contain few megafossils, but recent age determinations by micropaleontological methods of Mesozoic rocks in northern Alaska have shown what could be done if such work were extended throughout the Territory.

In the Yukon and the Cordilleran part of Mackenzie, many aspects of stratigraphy and structure await further study. For example, much of the Yukon Plateau consists of metamorphosed, stratified rocks, referred to as the "Yukon group", of which the age, succession, and structure present a multitude of problems. Not only does the altered condition of the rocks make the solution difficult, but their concealment by overburden and by younger rocks, and their interruption by many intrusions frequently prevent the tracing of marked horizons. The main problems are establishing the succession and

correlation within the group, and determining the age. These problems are followed by those of correlating the structure of infolded or downfaulted areas of somewhat similar rocks, which by slight differences of composition and metamorphism and, in some instances, the presence of organic remains, suggest a younger age. Recent work by H. Gabrielse of the Geological Survey of Canada, in northern British Columbia, close to the Yukon, has revealed excellently preserved Lower Cambrian fossils in strata apparently overlying a great thickness of metamorphosed sedimentary rocks. Farther north, similar strata occur in the Yukon group. Thus, while most of the Yukon group is generally believed to be Precambrian, some rocks included in it may be Paleozoic, while others may be divisible from the main part as late Precambrian.

In the mountains around the Yukon Plateau the Paleozoic is present nearly everywhere. To the northeast in the Mackenzie Mountains a relatively complete section seems to await study: the Paleozoic appears in considerable thicknesses and, though large gaps occur in the succession, all the major periods are represented somewhere.

The relationships of the Upper Paleozoic and the Mesozoic in the Yukon Plateau present a variety of problems. Determinable faunas of Carboniferous, Permian, Triassic, and Jurassic ages have all been found, but persistent fossil horizons are usually rare. Moreover the general lithological similarities, and the intermingled masses of volcanic materials, make the understanding of their stratigraphy and structure extremely difficult. The early Mesozoic, however, is relatively well represented with several fossil horizons, and is now being studied by F. T. Tozer of the Geological Survey of Canada.

The Upper Mesozoic marine strata are unconformably overlain by a great assemblage of coarse, continental, clastic, sedimentary rocks with small amounts of volcanic material interbedded. The upper part of this assemblage, the Tantalus coal measures, is dated by its early Lower Cretaceous flora, but the age of the lower part, generally considered to be Jurassic, is uncertain. The Tantalus measures are overlain by a huge mass of volcanic rocks very similar to those mixed with the earlier Mesozoic and late Paleozoic. An analysis of the stratigraphy and structure of this mass of strata presents many intricate and difficult problems particularly in view of the general lack of fossils in the Upper Mesozoic.

The late Mesozoic volcanic rocks and the Tantalus measures are invaded by granitic intrusions, and are truncated by the erosion surface on which the Tertiary rocks rest. The whole interval at the close of the Mesozoic in the Yukon is poorly understood. The volcanic rocks are grouped together on such uncertain bases as lithology and distribution, and show obscure or varied relationships with the different intrusions and older strata. Determination of the succession, structure, and history of these rocks and their correlation with events at the close of the Mesozoic and opening of the Tertiary are major problems.

The earliest Tertiary rocks in the Yukon are continental, clastic, sedimentary strata showing extreme variations in consolidation, and usually some

warping and faulting. They commonly lie in depressions or valleys of steep relief in the dissected surface of the older rocks. In earlier explorations their floras were dated as Eocene, but those found in recent years are placed in the Paleocene. As in Alaska, the correct dating and sorting out of the many basins of these rocks requires broad study.

The Tertiary sedimentary beds are overlain by volcanic rocks, scattered in large and small patches over the Yukon Plateau and parts of the encircling ranges. These rocks exhibit different relationships from place to place. In some localities they are tilted and truncated by the mid-Tertiary or later erosion surfaces. In others they are spread upon it, and elsewhere they lie at various levels of dissection in its valleys. The record of the Tertiary history of the Yukon contained in them awaits assembling from a regional study.

Much of the western Yukon escaped Pleistocene glaciation. Mapping has now traced the general outline of the irregular front of the ice during its last major advance. More than one advance is recorded in several widely separated localities, and the earlier movements in most cases are the more extensive. These advances have left a sequence of deposits that overlap the gravels and other deposits of the unglaciated region. Together, these phenomena contain an intriguing record of the geological events of the region from the present back into the Pleistocene, and perhaps to the late Tertiary.

In the northern Yukon there has been little exploration on the ground, but air photography has been particularly valuable in delineating the broad geological features. The Porcupine Plain is revealed as an area of relatively flat-lying rocks and few outcrops, while in the surrounding mountains thick sections are exposed where the upturned strata and remarkable open structures of the ridges around the borders resemble those of the Appalachians, and also of the Parry Islands in the Arctic Archipelago. Sections of Tertiary, Mesozoic, Paleozoic, and even Precambrian sedimentary rocks are known in the ranges of the northern Yukon. During 1953 much of this region was explored in a search for oil and metals, and new information on it is expected to be available shortly. But geological exploration is still in too early a stage to pick out problems.

East of the Cordillera in Mackenzie and Keewatin, exploration is still in a preliminary stage, but "Operation Keewatin" extended the knowledge of the Precambrian section, revealing that the areas of Precambrian sedimentary and volcanic rocks are larger than previously supposed, and that many members, previously regarded as Archean, are of Proterozoic age. The sequence of the Precambrian strata in this region presents many interesting problems.

In recent years the discoveries of large deposits of iron ore in Ungava have led to the detailed study of the stratigraphy and structure of the Labrador Trough and the search for areas of similar rocks in the surrounding region. In the northern or subarctic parts of Ungava such rocks have been discovered only in the northern extension of the trough to the west of Ungava Bay and in a belt extending from Wakeham Bay to Cape Smith. The correlation of the rocks of the trough with those of the belt, and again with those of the Belcher Island and Nastapoka Bay group are the main problems.

Franklin is less known than the other districts but the widespread pattern of the explorations dating back to the early nineteenth century forms the skeleton of a remarkably complete general picture of the region. Many of its chief geological features and problems are set out by Y. O. Fortier and R. Thorsteinsson in their important paper on the Parry Islands folded belt.[1] The platform of the Precambrian Shield, composed of old crystalline rocks mantled in part by Proterozoic strata, slopes generally west from the highlands of Baffin, Devon, and southeastern Ellesmere islands, and very gently north from the mainland. In the southern part its surface is characterized by broad undulations whose hollows contain wide basins of both Proterozoic and Paleozoic strata. As a whole the rocks become progressively younger northwestward passing from Proterozoic through Paleozoic to Mesozoic and Tertiary.

In the south, between the waters of M'Clure Strait and Viscount Melville and Lancaster sounds and the mainland, broad ridges of the Precambrian rocks separated by basins of Paleozoic strata present many interesting subjects for study in Precambrian succession and Precambrian–Paleozoic relationships. The Paleozoic sections of the basins also contain many problems. Northward, in a broad arc from Melville Island to the northeast coast of Ellesmere Island and northern Greenland, belts of folded Paleozoic and Mesozoic strata form the Innuitian Region, which presents numerous problems of stratigraphy and structure. Northwest of this region the geology is even less known, though Mesozoic and Tertiary rocks, including some of both extrusive and intrusive origins have been found.

The government surveys have expended much of their effort on stratigraphy and structure, and notable advances are anticipated in the next few years. Nevertheless, these are large and important fields, and ample room remains in them for appropriate attack by other research scientists. Many of the fields will involve work in areas which are relatively inaccessible and isolated by long distances, and are therefore expensive to operate in. Economy of cost and efficiency of effort can be greatly enhanced by close cooperation among workers interested in different branches of science and by the joint use of existing facilities.

Geomorphology

The geomorphology of arctic and subarctic areas has been attracting substantial attention over the last few years. Much of this work has been a by-product of other investigations, but some has been done for its own merit. At present the greatest need is for a better grasp of such processes as rock disintegration, transportation, and sedimentation. While geomorphology in the north has probably been receiving about as much attention as other aspects of geological research, it is unlikely that the field will be fully occupied either by the government agencies or by mining companies, although some work has been done by both.

[1]Fortier, Y. O. and R. Thorsteinsson. 1953. "The Parry Islands folded belt in the Canadian Arctic Archipelago". *Amer. J. Sci.* Vol. 251, pp. 259–67.

In appraising the need for additional geomorphological research in the Arctic it should be remembered that the validity of conclusions in this type of research frequently depends on adequate bedrock maps and adequate knowledge of pre-Quaternary stratigraphy. In Alaska, substantial advances in geomorphology have recently been made, especially through projects of the Alaska Terrain and Permafrost Unit of the Military Geology Branch of the U.S. Geological Survey. Areas in Alaska where geomorphological information is lacking or scanty, and in which little or no research to our knowledge is now being done include:

(1) The southern front of the Brooks Range. Investigations should be undertaken preferably in conjunction with geological mapping on the same scale as, and after the completion of, adequate base maps.

(2) The Ray Mountains and the Koyukuk River basin.

(3) The lower Yukon River area.

(4) The Alaska Range between the head of the Nushagak River and the upper Kuskokwim River area, and between the upper Kuskokwim and the McKinley tributary of the Kantishna River.

(5) The Wrangell Mountains and the basin of the White River. Much important information regarding the geomorphological history of Alaska could be obtained in this area, where early Tertiary tills and an almost complete Tertiary volcanic sequence are reported. Good base maps presumably will be available in a few years. The work should be done in conjunction with remapping of the bedrock on an adequate scale.

(6) The basin of the Fortymile River and other parts of the Yukon–Tanana plateau.

(7) The western part of the Susitna River basin. Geomorphological studies could well be made in conjunction with the mapping of the coal resources of the Tyonek area and the gold placers of the Peters Hills.

The following studies should throw more light on geomorphological history:

(1) A study of the Yukon–Tanana plateau with special reference to origin and date of deposition of gold placers. In the Fairbanks district work should concentrate on pre-Wisconsin history.

(2) Geomorphological reconnaissance of Alaska, primarily to work out the preglacial geomorphological development of the Territory. This would consist of (a) intensive review of the literature and reading of old field notes, followed by (b) discussions with field geologists of geomorphological problems and evidence in their areas, followed by (c) study of air photographs, testing and developing hypotheses gained in parts (a) and (b), followed by (d) one or two seasons of intensive reconnaissance along existing routes of travel, to check and develop hypotheses, followed by (e) one or two seasons of intensive helicopter-borne reconnaissance. This would be at least a 6-year project. Its immediate economic value is in connection with gold placers.

In northern Canada the study of geomorphology has received little attention. The essential need is for a better grasp of the working of geomorphological processes characteristic of the north. In the Yukon, on the

border of the region where arctic processes are active, the main features appear to owe their character to those processes normal throughout most of Canada, but surface features are, at least, modified by such arctic processes as solifluction. Eastward and northward from the southern Yukon, the processes of the Arctic become more important in their bearing on the development of land forms. In Franklin, particularly, they are at a maximum. Here the problem is first to recognize the relative importance of marine submergence, glaciation, and such distinct arctic processes as solifluction, which now commonly mask features of other origins. The less conspicuous processes too, require study. For instance, the effects of erosion by the hard, sandy snow, driven so continuously by the wind against the outcrops of the arctic deserts through long winters, solution of rock by the cold waters, and chemical decomposition of rock under arctic conditions, all need proper evaluation before arctic geomorphology can be fully interpreted.

Ground water and engineering geology

Up to recent years, the subjects of water supply and sewage disposal have not been considered pressing in the Arctic and Subarctic. Actually, such problems have always existed and have always been closely related to the health situation of both native peoples and white inhabitants. With the coming of larger settlements and military establishments to the north, these problems have become critical. Water-supply and sewage-disposal problems are shared by surface-water and ground-water specialists. Surface water is dealt with in the field of hydrology and hence is not included in the scope of this paper. Ground water lies clearly within the bounds of geology.

It now seems inevitable that ground-water geology must play an important role in northern development. Already some of the larger communities such as Anchorage and Fairbanks are facing serious water problems that may well be solved in large part by the further development of ground-water supplies. Ground-water research appears to be largely a responsibility shared by the government surveys and the communities involved. At least two systematic government studies have been made in this field in Alaska. One of these applies specifically to the Anchorage area, and the other is of more general scope applying to all permafrost areas, and emphasizing ground-water principles rather than ground-water conditions in specific areas. In addition, a preliminary report on permafrost in the Fairbanks area, which briefly considers ground water, has recently been declassified and made available to the public.

While ground-water principles, as generally understood, apply in large parts of the Subarctic, new principles and new factors need to be appraised for permafrost areas. Thus ground-water geology in the north is closely related to both the permafrost and the geomorphological fields.

The application of geology to engineering works of various kinds such as highways, dams, tunnels, and foundations, and to deposits of such construction materials as sand, gravel, and clay, has long been a useful practice. This type of geological work has come to be known as engineering geology. In

the past ten years or so the value of engineering geology has become increasingly appreciated until now it has assumed an important place in geological work.

The need for engineering geology is especially great in the Arctic and Subarctic. Here special problems of foundations for large structures and for such works as highways, dams, and airfields, are created by the presence of permafrost, by the thick ice that annually forms on streams and lakes, by severe frost action, by wide stream valleys, by great variation in stream flow, by floating ice, and by many other factors.

In Alaska, the U.S. Geological Survey has carried on a number of engineering geology projects; some of these were projects of the Military Geology Branch. An engineering geology study has been made of the Anchorage area. A study involving engineering geology has been carried on at Fairbanks and in the Dunbar vicinity west of Fairbanks. Similar studies have been made in a few other places and a few special projects have been carried on, such as the study of slide problems along the Nenana River gorge as related to railroad maintenance. A full-time engineering geologist has now been stationed in Alaska by the U.S. Geological Survey to work on principles needed in coping with highway and other pressing problems.

Engineering geology in the north shares with other branches of geology certain limitations imposed by inadequate knowledge of some geological processes. It is, however, a field which can make extraordinary contributions to northern development, and in which the governments must participate to a large extent. At present, the most pressing need is probably for research on the principles, whose application will then be the special responsibility of smaller government units, such as provinces, territories, and municipalities, and of private groups, such as contracting firms and mining companies.

The limits to present knowledge in geology and geomorphology have been emphasized throughout this paper, because an understanding of them is necessary for appraising the relative values of proposed research programs. In addition, the paper has pointed out some opportunities open to geologists in the Arctic and Subarctic; opportunities which are now far greater than the anticipated supply of geologists. The failure of universities to stimulate interest in northern research may be partly responsible for this scarcity of arctic geologists. Another factor may be the difficulties facing scientists in isolated northern regions. But the great demand for results from the north, and the opportunity for working in little-known fields where individual initiative is both required and rewarded should be ample compensation for any difficulties involved. It is hoped that this paper, although incomplete, may serve as a guide and stimulus to future geological and geomorphological research.

GLACIOLOGY

P. D. Baird* and R. P. Sharp†

A Brief Review of the Recent History of the Science. By P. D. Baird

The science of glaciology is scarcely a century old. For many years it was treated rather lightly, mostly by geologists who happened to be also enthusiastic mountain climbers. It took a long time for men to realize that to explain some of the phenomena of past glaciation and the problems of Pleistocene geology a deeper study of the processes of existing glaciers was necessary. This concept was stimulated greatly during the past thirty years by the now classical investigations of Hans W:son Ahlmann (1948) in several areas around the North Atlantic Basin.

It can be argued that wherever perennial snow and ice is found in the form of ice cap or glacier we have a glacial climate, hence all glaciers in any part of the world are "arctic". Yet it seems that there are important physical differences between glaciers in temperate latitudes and those in polar regions, and Ahlmann has divided them in his geophysical classification on the basis of temperature and consistency of the upper parts of the glaciers.

Thus although many problems in glaciology, particularly those dependent on long-term observations, can most easily be studied in accessible, temperate glaciers, there are still some questions which can only be answered in the polar regions where strongly negative temperatures prevail in the glacial ice and in the firn snow above it.

In the North American Arctic the geographical extent of all land ice has still to be properly delimited. This would now be possible from a detailed study of existing air photographs, and a tentative classification of the glaciers could be made with the aid of spot field checks.

In recent years there has probably been more glaciological activity in Greenland than in Alaska or Canada. In 1939 Ahlmann's work in the North Atlantic area carried him as far as Greenland, to the Frøya Gletscher in latitude 74°N. on the east coast (1941). Immediately after the Second World War P.-E. Victor began organizing the Expéditions Polaires Françaises, which resulted in their large-scale Greenland project of the summers 1948–51 and the winters 1949–50 and 1950–1. A tremendous amount of glaciological work was achieved (Cailleux, 1952), and new ideas about the Greenland Ice Cap were formulated. Seismic soundings have now shown that at many places

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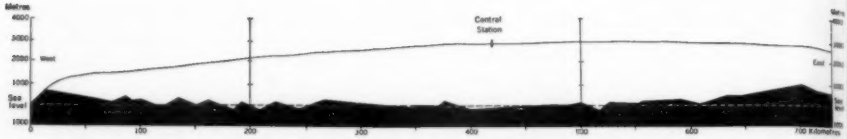

Fig. 1. The Greenland Ice Cap on a section approximately at 70°N., after the Expéditions Polaires Françaises 1948–51. From A. Joset reproduced by Cailleux (1952, p. 8).

the rock floor under the ice is at, or even below, sea level (Fig. 1). Based on these Greenland results J. F. Nye (1952) evolved a theoretical relationship between the thickness of an ice cap and its surface slope. By his calculations the rock floor in north Greenland, an area where British and American parties have recently operated, may be very greatly below sea level. We hope soon to have direct evidence on this point.

Next to Greenland Canada possesses most arctic ice, but until recently little glaciological work has been attempted. In 1950 the Arctic Institute's Baffin Island expedition investigated the Barnes Icecap (Baird *et al.*, 1951). This appears to be a relic of the Pleistocene age and is maintained chiefly by the refreezing of the annual meltwater on to the cold high Polar Ice, and not by normal accumulation of firn slowly changing to ice. There have been two further expeditions to Baffin Island. In 1952 a small party visited the Grinnell Glacier in southern Baffin Island, and in 1953 the Arctic Institute's expedition studied the Penny Highland, the second highest region of the Canadian Arctic.

Two other major projects in Canada should be mentioned. In 1952, under the direction of R. P. Sharp, a program of long-range investigation of many of the least known properties of glacial ice was started on the Saskatchewan Glacier, a readily accessible, temperate glacier in the Rocky Mountains. In 1953 G. Hattersley-Smith and R. Blackadar made a preliminary reconnaissance of the ice shelf off the north coast of Ellesmere Island in preparation for a joint Canadian/United States expedition the following year. This joint expedition spent the summer of 1954 making detailed studies of the shelf, which is believed to be the source area for the ice islands observed in the Polar Basin.

In the Alaska–Canada boundary area two large projects have been under way since 1948. The Arctic Institute, under the leadership of Walter Wood, has carried out work on the Seward–Malaspina system (Sharp, 1951), while the American Geographical Society has studied the Juneau Ice Field (Field and Miller, 1950). These projects were the first large three-dimensional surveys of glacial systems to be carried out in North America. On the Malaspina Glacier a bore hole 1,000 feet deep has been sunk, and inclinometer measurements should yield important results on glacial flow at depth. On the Juneau Ice Field core samples of ice have been obtained down to about 300 feet. Great fluctuations from year to year in precipitation and ablation have been recorded, and a start has been made in both areas on winter studies.

Recent North American work in the Polar Basin has largely concentrated on problems connected with ice islands. Since 1946 the existence of very

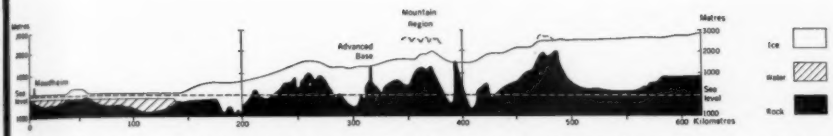

Fig. 2. The Antarctic Ice Cap on a section approximately southeast from Maudheim, after the Norwegian-British-Swedish Antarctic expedition. From Robin (1953, p. 57).

large stable ice masses floating in the Polar Basin has been known, and some of their tracks have been plotted by crews of the U.S.A.F. and R.C.A.F. (Koenig *et al.*, 1952). On 19 March 1952 the first landing was made on one of these ice islands, known as T3, in a position 103 miles from the north pole, and a semi-permanent base was subsequently established by the U.S.A.F. A program of scientific observations was carried out and regular weather observations were transmitted until May 1954 when the ice island was abandoned.[1] The thickness of T3 averages about 200 feet, and borings to 60 feet have shown a mainly freshwater origin, although at the lower limit there are traces of salt. There has been considerable Russian activity in the Polar Basin and some news of their work is just becoming available.

Outside the North American Arctic other glacial studies are being pursued and should be noted here because their evidence is essential in assessing such problems as "the warming of the Arctic". The Norsk Polarinstitutt now has a glaciologist on its staff who is responsible for investigations both in Norway and Svalbard. A clearly defined mountain glacier, Storbreen, and a swiftly moving tongue from Jostedalsbreen have been selected for continued study, as has Finsterwaldbreen in Vestspitsbergen.

In Iceland a glaciological society has recently been formed and has established a small research station on the Vatnajökull (*Jökull*, 1951).

Results from the large Norwegian-Swedish-British Antarctic expedition (Robin, 1952), in which a study of the glaciology of the antarctic continent was a principal consideration, have shown that the season 1950–1 was one of glacial equilibrium in Queen Maud Land and that there appears to have been no appreciable thinning of that section of the antarctic ice cap in the past decade. Seismic soundings showed over 2,000 metres of ice thickness inland, and borings were made with core examinations up to 70 metres deep on the ice shelf at the expedition base (Fig. 2).

From these widespread studies we are beginning to gain a picture of the extent of the recent rather alarming retreat of glaciers (*see* Figs. 3–6). This appears to be progressing violently in the European area and the Pacific coast, less violently in arctic North America, and scarcely, if at all, in the Antarctic.

The future, as R. P. Sharp points out, should lie with detailed examinations of selected accessible glaciers. At present there is tremendous activity on these lines in Switzerland. The volume of valuable detailed glaciological research carried out there probably exceeds that of the rest of the world.

[1] A small United States party reoccupied the station in April 1955, and planned to remain for the spring and summer months making scientific observations. *Ed.*

Photo: U.S. Coast & Geodet. Surv., Coll. Comm. on Glaciers, Amer. Geophys. Un.

Fig. 3. North Dawes Glacier, Endicott Arm, Alaska, in 1889, showing a party from the U.S. Coast and Geodetic Survey vessel *Patterson* which made the first determination of the position of the terminus of the glacier.

Photo: W. O. Field

Fig. 4. North Dawes Glacier in 1935, when the terminus had receded about 3,900 feet since 1889.

Photo: W. O. Field

Fig. 5. North Dawes Glacier in 1941.

Photo: Amer. Geogr. Soc.

Fig. 6. Valley of the North Dawes Glacier in 1950. Total recession from 1889 to 1950 was approximately 6,500 feet.

Most meticulous surveys have been made of some of the larger glaciers, and by means of tunnels, sponsored by hydroelectric concerns, much is being learned about internal structure of ice masses.

The polar explorer and scientist is intimately interested in the climate both present and past. The study of glaciers is one of the most valuable in the elucidation of climatic history. As we move back in time, glacial geology takes over from pure glaciology as the science concerned with collecting the evidence. We are back to the geologist again. But the fields of meteorology, physics, and botany have been drawn in, and the practical work of the engineer is required to assist the field investigator, who must still have a strong back and a love for snow and ice.

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Some Aspects of Glaciological Research. By Robert P. Sharp[1]

The following brief comments make no pretence at providing a complete survey of desirable research in glaciology. The aim is rather to "sign post" the beginnings of trails that might be followed by interested workers. These investigators must themselves become well informed on the basic principles, so they can independently evaluate the desirability of a specific program and determine the best means of carrying it forth. No one can or should try to tell someone else how to tackle a research problem. They can only indicate some of the areas that appear worthy of consideration, and that is the objective here.

Velocity relations in glaciers

Differential movements within glaciers, both in time and space, have been recorded for more than a century (Forbes, 1843, pp. 124–56). In view of this

[1]Contribution No. 666, Division of Geological Sciences, California Institute of Technology.

extended observation and the data obtained (Hess, 1904, pp. 115–50; Klebelsberg, 1948, pp. 80–9), it is truly surprising that so much remains to be done. Large, relatively untouched but highly promising areas of investigation in the field of velocity relations invite attack. For ease of discussion, differences in surface velocities are treated, first with respect to spatial relations and then with respect to temporal variations. This is followed by consideration of velocities at depth in glaciers.

Surface velocities: Many studies on different valley glaciers provide a reasonably good picture of velocity distribution along transverse profiles on the surface. More efforts should be directed toward obtaining data on velocities over the entire surface of the glacier, as only a little information of this type is available (Hess, 1904, p. 136). This will have to be done by means of carefully controlled measurements at a network of widely distributed points and not just along two or three profile lines. At the same time information should be obtained that will allow an evaluation of the influence on flow velocity of surface slope and channel characteristics, especially width and depth.

If velocity studies are possible only along profile lines, efforts should be focused on longitudinal profiles. Such data are of prime importance as a means of testing theoretical concepts bearing on extending and compressive flow in glaciers (Nye, 1952, p. 89). Little information is available on longitudinal velocity changes in North American glaciers (Matthes, 1946, pp. 222–5; Matthes and Phillip, 1943, p. 21). The situation is better for European glaciers (Hess, 1904, pp. 128–35, 148; 1933, pp. 37–8), but quantitative data are needed.

Nearly all measurements of surface velocity to date have recorded only the downvalley component parallel to the glacier surface. It has long been recognized that the absolute direction of movement is actually oblique to the surface and of different angles and different amounts from place to place (Hess, 1933, p. 41). The failure to build upon Reid's (1896, pp. 917–21; 1901, pp. 749–50) early work on this matter is a striking oversight, and this remains a promising and fertile line of investigation.

Variations of flow velocity in time constitute a closely allied subject for study. Although more and better quantitative data on seasonal velocity fluctuations would be useful, measurements over shorter periods provide an even more fruitful line of investigation. Such measurements must be carefully controlled or the data will be open to such question and uncertainty as to make them almost worthless. Some earlier investigations of short-period variations have not been rigorously controlled, and most, if not all, have been made with respect to a single station on the glacier surface. Indications are that the care and labour required to make reliable short-period measurements at a number of stations will be well worth the trouble. Preliminary studies on the Saskatchewan Glacier (Meier *et al.*, 1954, pp. 9–12), show that surprising and puzzling differences of velocity occur from day to day between stations located in the same flow-line as well as beween stations in different flow-lines. Adjacent flow-lines are not always coordinated in their periods of acceleration

or deceleration, and different parts of the same flow-line behave differently during the same interval. It seems that much can be learned about the nature of glacier movement from short-period observations of a number of points on the glacier surface.

Instances of exceptional acceleration and deceleration show a definite but unexplained correlation with major meteorological events, especially periods of precipitation. Much more field data on this type of relation must be gathered before even the crudest type of analysis from the standpoint of physical mechanics will be possible. Whether the erratic velocity behaviours involve some sort of wave movement within the ice, or whether the normal processes of flow respond directly and sensitively to variations in the meteorological elements cannot be determined on the basis of present information.

The movement of waves or surges through a glacier needs more study. Such surges have been recognized (Hess, 1931, p. 240, 1933, pp. 94–5; Finsterwalder, 1937, p. 99; Streiff-Becker, 1938, pp. 18–19; Klebelsberg, 1948, pp. 87–8), and one is currently progressing down the Nisqually Glacier on Mount Rainier in Washington (Harrison, 1951, p. 11). It is of utmost importance that these phenomena be carefully observed and their various behaviours recorded. An understanding of the mechanics involved would certainly further our knowledge of glacier flow. In addition, they are obviously important in causing erratic advances at the terminus of a glacier.

Glaciology, like many other phases of earth sciences, is currently passing from a stage of general observation to one of more careful quantitative measurement. The temporal and spatial differences of velocities in glaciers are good subjects for this type of study.

Velocity relations at depth: Little is known about the distribution of velocity with depth in glaciers, although such information is even more essential to an understanding of glacier flow than surface data. Considerable information on stress–strain conditions at depth, and on the physical properties and behaviour of ice under confining pressures, as they occur under natural conditions, can be gained from the vertical velocity profile in a glacier.

Data on velocities at depth are scant because they are difficult to obtain, but their value justifies the effort. A bare beginning has been made, and more data should be gathered from ice streams on slopes and ice sheets on flats. Those interested in this type of investigation can learn of procedures previously used from the following references: Gerrard, Perutz, and Roch (1952) and Sharp (1953).

Structures in glaciers

Glaciology offers many problems for study, but if an attempt were made to select a few of basic importance, the subject of glacier flow would certainly be among them. Attacks on this problem can be made from various directions and should include both field and laboratory investigations. One avenue of field approach is through study of structures within glaciers. Since most of

these structures have been created by or because of flowage, knowledge of them and their origin is bound to promote understanding of the mode and mechanism of glacier flow.

Planar structures: Crevasses and faults are surface features, to be sure, but they are the product of stresses generated in the crustal ice by movements deeper within the glacier. Field studies of crevasses have not kept pace with theoretical analyses of the stresses leading to their formation (Lagally, 1929; Nye, 1952, pp. 89–91). Brief field inspection shows that crevasses are more varied and complex than might be supposed. Many different types can be recognized, and each type must have a particular meaning with respect to stress conditions in the glacier. Crevasses need the attention of someone well versed in solid state physics and engineering principles dealing with stress, strain, and the behaviour of brittle materials. Faults should also be studied, for they are just as significant, and perhaps easier to interpret.

A thorough investigation of foliation in glacier ice would likewise be desirable. A satisfactory explanation of its origin, and an understanding of the attitude and structure of foliation planes in various parts of the glacier are lacking. Most investigators regard foliation as a secondary structure imposed on the ice by flowage, but a few look upon it as wholly or in part a relic of sedimentary layering inherited from the firn. However, even among those regarding foliation as secondary, the mode of origin is a subject of some debate. This is a matter intimately related to the mechanics of glacier flow, and an understanding of either is likely to be promoted by advances in the other. A satisfactory explanation is also lacking for the fact that the spoon-shaped structure of foliation planes, observed near the terminus of a simple valley glacier, does not extend any distance up the glacier, at least on the surface.

In recent years geologists have made considerable progress in understanding the form and emplacement of relatively homogeneous igneous bodies through careful mapping of all structures displayed therein. Similar investigations of glaciers might prove fruitful if all crevasses, faults, foliation planes, debris layers, sedimentary structures, lineation (if any can be recognized) and related features were mapped. This would be difficult to do because structures in glaciers are usually so profuse and locally so complex that detailed mapping leads more to frustration and confusion than to clarification and understanding. Anyone undertaking such a study should select the smallest, simplest glacier available as an initial subject.

Rhythmic banding (ogives) in steep valley glaciers deserves further investigation because it in turn can lead to an understanding of the mechanics and behaviour of these ice streams (Leighton, 1951). The interrelation of individual ice streams in compound valley glaciers, and the origin of the complexly deformed debris layers displayed by many ice masses present unsolved problems worthy of study.

Crystal fabrics: Investigations of crystal fabrics in glaciers are undergoing the same history as the earlier studies of fabrics in rocks. Strong orientation patterns have been demonstrated, but no satisfactory explanation

for them has yet been evolved. This comes about in large part because knowledge of the behaviour of polycrystalline aggregates of ice under stress is so incomplete. Laboratory investigations are clearly called for, and a beginning is being made in this direction, particularly by J. W. Glen in England, and by D. T. Griggs and G. P. Rigsby in the United States.

It is entirely possible that the strong crystallographic orientations demonstrated in ice at the glacier's surface (Rigsby, 1951, 1953) are the product of an ordered recrystallization proceeding from an orientation earlier established by flowage at depth. A study of ice samples obtained from considerable depth by coring would be helpful in evaluating this hypothesis, if the relaxation rate is not too rapid and if the specimen is not too greatly disturbed by the coring procedure. Core drilling in glaciers has so far been too shallow for such purposes (Miller, 1953, p. 14), but this matter should be pursued further.

Much remains to be done with field studies of crystal fabrics, and a recent suggestion that shear planes of several different orientations in the glacier are involved merits further investigation (Schwarzacher and Untersteiner, 1953, pp. 121–4). However, the greater need at the moment is for controlled laboratory experimentation to establish the principles by which preferred orientations are developed in aggregates of ice crystals.

Phase relations in glacier ice

In 1950 H. Bader made an exploratory study of relations between the liquid, vapour, and solid phases of water in glaciers with respect to the conditions of temperature and pressure to which the ice had been subjected. This work was largely preliminary in nature, and the results obtained were different from those expected. Nonetheless, it appears that much can be learned concerning the properties and behaviour of ice at depth within a glacier from investigations of phase relations. Some of this work can best be done in the field, as the laboratory cannot reproduce wholly satisfactorily the conditions to which the ice in glaciers is subjected.

Oxygen-isotope studies in snow, firn, and glacier ice

Pioneer investigations of oxygen-isotope ratios (O^{18}/O^{16}) in waters of various origins reveal that water in glaciers is exceptionally light, that is low in O^{18} (Epstein and Mayeda, 1953). Furthermore, preliminary studies show sizeable differences in the O^{18}/O^{16} ratio within a single glacier. Data are still too scanty to demonstrate any consistent trends in the oxygen-isotope ratios in glaciers or to relate them to other factors, but these differences may well reflect environmental conditions at the point of origin of the ice, or they may be influenced by something within the subsequent history of the ice such as age, amount of flow and recrystallization, and temperature regime. This type of investigation is in its earliest stages, but it looks promising. Close cooperation between the geochemist and the field glaciologist will be required to produce results.

Micrometeorology and the regime of glaciers

Micrometeorology has been studied for some time with vigour and profit in Scandinavian areas (Wallén, 1948), but it has been largely neglected in North America, save for some work currently underway (Hubley, 1953). Glaciers are frequently referred to as "historians of weather", but weather records from glaciers cannot be interpreted without an understanding of how they respond to the various meteorological factors. Furthermore, the relative influence of the several meteorological elements involved displays such gross variation, depending upon environment, that detailed studies on many different glaciers in many different areas will be required before an evaluation of the basic relations will be possible.

A means of checking the reliability of micrometeorological studies is available if a correspondingly accurate determination of the ablation of firn and snow can be made. Measurements of ablation to date have been too crude and inaccurate to provide reliable values for balancing the ablation equation. It is not feasible to go into details here concerning the difficulty of making an accurate measure of ablation in firn or snow (Hubley, 1953, p. 18). It is a difficult matter, but one well worth considerable study and effort.

Micrometeorological studies on glaciers have significance outside the field of glaciology. The proper evaluation and understanding of climatic changes recorded by present and past glacier behaviours have a bearing on all activities of mankind affected by the climatic environment. The science of meteorology should also benefit, as a glacier surface furnishes an ideal subject for studies of heat exchange at the earth's surface.

Closely allied with the subject of glacier response to climatic change is the synchronism or non-synchronism of glacier behaviours in widely separated regions. When one deals with ancient fluctuations of glaciers the techniques of glacial stratigraphy and geobotany come into play, but even these ancient fluctuations should be interpreted on the basis of sound glaciological and micrometeorological principles. Eventually, Carbon-14 dating may be helpful in establishing the more ancient relations, provided the method can be properly refined and applied to the problem. A demonstration of closely synchronous glaciations in opposite hemispheres, with some degree of antiquity, would have major significance with respect to theories bearing on causes of glaciation.

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PERMAFROST RESEARCH

R. F. Legget*

"PERMAFROST" is a term now widely used to describe perennially frozen ground, a phenomenon which is peculiar to cold regions and at once of unusual scientific interest and of great practical significance. "Pergelisol" has been suggested (Bryan, 1946) as a more accurate name for this ground condition and "cryology" for its study, but the problems introduced into the development of arctic and subarctic areas by perennially frozen ground are becoming well known, and popular usage already appears to have eliminated the possibility of these desirable semantic clarifications. Some of the specialized problems concerned with permafrost are discussed in the papers on geophysical exploration, geology, agriculture, and meteorology in this volume; here the subject will be considered as a whole and the research which has been started and the challenging problems which face those engaged in this branch of scientific enquiry will be outlined.

It is not surprising to find that a large proportion of the surface layers of the northern land mass of the world is always at a temperature below freezing point. It is not generally appreciated, however, that about one-half of the area of Canada (Jenness, 1949) and as much as one-fifth of the land area of the world is perennially frozen near its surface (Muller, 1945). Some of this vast area consists of exposures of solid rock, the properties of which are not significantly changed by freezing or thawing. But when soils or coarsely crystalline rocks form the surface of the ground, especially if water is present in them, their character may be markedly affected by changes of temperature above or below freezing point. The term "permafrost" should correctly be used to describe all parts of the earth's surface which are consistently below a temperature of 0°C, and not merely perennially frozen soil.

Permafrost is no new phenomenon. It is at least contemporaneous with the present cycle of climatic conditions in the Arctic. It was recognized by Alexander Mackenzie and by other early travellers in the north but it is only in comparatively recent years that it has become a problem. As long as water in the summer and snow in the winter provided necessary transportation routes, and with buildings of simple design, the summer thawing out of permafrost was unimportant. When, however, frozen ground had to be cleared, first for road construction and then for the building of airfields, and with the advent of heated basements for buildings, the peculiar properties of permafrost made themselves very evident, especially to engineers. At the same time, the

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rapid extension of scientific work in the north has also automatically directed the attention of geologists in particular to a ground phenomenon which had for long been neglected.

Within the last decade, therefore, active programs of permafrost research have been started by United States authorities in Alaska, and even more recently similar work has been commenced in Canada. Individual studies had naturally been carried out previously, but an integrated approach to this problem is yet another development that resulted from the Second World War, for it was the building of the Alaska Highway and the construction of northern airfields which showed vividly how little was known about this peculiar feature of northern regions.

Detailed investigations were made along the Alaska Highway by United States authorities (Eager and Pryor, 1945). The U.S. Army Corps of Engineers subsequently established (under their St. Paul District Office) a field research station near Fairbanks (*Civil Engineering*, 1947), which is now under the direction of the Arctic Construction and Frost Effects Laboratory of the U.S. Army Corps of Engineers at Boston. This station has already carried out notable experimental work. It has since been joined in its efforts by the Snow, Ice and Permafrost Research Establishment of the U.S. Army Corps of Engineers, located at Wilmette, Illinois, whose mission is to perform research for and to coordinate the research program of the U.S. Department of Defense. The U.S. Geological Survey has had members of its staff engaged upon detailed field studies of permafrost, some of this work being linked with that of the U.S. Naval Petroleum Reserve at Point Barrow (Black, 1951). The programs of these several organizations in Alaska constitute the outstanding contribution to permafrost research in North America; although much of the work has been classified in character, enough records have been published to indicate the great value of the results obtained.

Development along the Mackenzie River Valley, the building of the Hudson Bay Railway, and the steady northern expansion of mining activity in the Dominion have combined to demonstrate to Canadians some of the problems associated with permafrost, but the knowledge and experience thus gained have not been widely circulated. The development of the small oil refinery at Norman Wells by Imperial Oil Limited, and the associated wartime Canol project, resulted in rather more detailed investigations (Hemstock, 1952) of this interesting area.

It was therefore not surprising when, after a survey of permafrost conditions in northern Canada, the Division of Building Research of the National Research Council of Canada selected Norman Wells as the site of its Northern Research Station. This was established in 1952 in cooperation with Imperial Oil Limited. It is intended that this station will be both a base for field and laboratory studies of permafrost, and a centre of information in connection with the special problems of building in the north of Canada. Work at Norman Wells is being started in close association with the United States organizations already noted so that duplication of effort will be obviated and integration of work ensured (Pihlainen, 1951).

All the problems connected with permafrost are determined by the local pattern of ground temperature. Temperatures in the ground are determined by the transfer of heat to the surface from the centre of the earth, representing a heat gain to the covering layer, and by the heat losses and heat gains at the surface, which are determined by the thermal environment above ground. Two distinct parts can be recognized in the heat exchange between surface and atmosphere, the conduction–convection heat exchange with the air and a radiant heat exchange with the sky. The former may at any given time represent a heat gain or a heat loss; the latter involves a large heat gain to the earth when the sun is shining, and a much smaller radiation exchange when the sun is not shining, which may be either a gain or a loss. Day-to-night variations in both air temperature and solar radiation may therefore cause a daily fluctuation in ground temperature, marked at the surface but extending only a few inches in depth because of the heat storage capacity of the earth. The yearly cycle is similar, but with the longer period the depth of influence may extend as much as 20 feet below the surface. There is also the possibility that a still longer cycle, involving geologic time intervals and therefore effective over a much greater depth, may also be involved. Other factors such as wind, snow cover, rainfall, evaporation, and vegetation cover may introduce variations in the thermal pattern, in addition to those inherent in air temperature and sunshine and in the physical properties of the ground (Legget and Peckover, 1949).

In southern Canada, it is usual for the ground to freeze in mid-winter although only to a relatively shallow depth. Because of the time-lag in temperature changes beneath the surface, the frost layer may be correspondingly lowered as the year advances, but, even in extreme cases, it will have disappeared by mid-summer. The annual mean temperature in this upper crust, about which the annual variations take place, appears usually to be very close to the mean annual local air temperature. The mean annual temperature of local ground water will be similar.

In areas where permafrost is encountered the local annual mean soil temperature is below freezing, but with the coming of summer the temperature of the upper crust will be raised above freezing point. This thawing will be evident only in those soils which contain water (clays and silts and some soil mixtures, sands, and gravels), and their consistency may change from being solid and rock-like to being wet and sloppy. This part of the soil which thaws out is called the "active layer". Its depth may vary locally from year to year but, under natural conditions, the variation will be small. The muskeg which is so prevalent over permafrost acts as an excellent insulating medium and tends to keep the active layer shallow.

When the muskeg, or any other natural cover, is removed, as in the clearing operations for road building, then the normal thermal pattern is lowered, frozen soil which has not previously been thawed will be so affected, and the problems of the engineer begin especially if, as is so frequently the case, the newly thawed-out soil has a high moisture content. If artificial heat, for instance from a heated basement, is applied to such frozen ground, then

Fig. 1. Thawing of frozen soil following clearing for road construction; the soil was a fine silt with such a high moisture content that it slumped and flowed as it thawed, once the vegetation cover was removed.

the problems created may extend throughout the year instead of being confined to the warm months of summer.

The problems demanding research in connection with permafrost almost suggest themselves from this brief outline. First, and perhaps most obvious, is the need for accurate knowledge of the distribution of permafrost so that those who have to plan operations in the north may know with certainty if they are going to work in a permafrost area, irrespective of the time of year when they have to make their site studies. This knowledge is essential for engineering operations, but it is also of importance for agriculture. Such regional survey research work is well advanced in Alaska, and investigation of the southern limit of permafrost has now been started on a detailed scale in Canada by the Division of Building Research of the National Research Council. The correlation of meteorological statistical studies with permafrost distribution is another major research task in which only a start has been made, and which could be attempted despite the scarcity of long-term climatic data for the north.

These approaches are regional in character and yet the practical problems which permafrost creates are usually quite local. Further advances must therefore be made in techniques of detecting permafrost with certainty and yet with a minimum expenditure of time and money. Aerial photo interpretation gives promise of aiding this work considerably (Woods *et al.*, 1948), both for detailed site surveys and for regional surveys, but much more work

is required in developing such aids as specific interpretation keys. Geophysical exploration methods have been used with considerable success in Alaska,[1] and much research is still being done along these lines.

The need for such detailed local information results from the fact that there is no regularity in the southern limit of permafrost, despite the smooth line which may be indicated on small-scale maps. Moreover, there may often be a conflict of local opinions as to whether permafrost is or is not present at a particular site. This may be due, in cases where the local soil is dry sand and gravel, to the absence of water, the dry material failing to reveal its frozen state through visual inspection alone. Since these soil conditions appear almost ideal for building sites, the possible change in ground conditions when vegetation cover is removed and surface drainage can enter such dry frozen ground may be serious. Little is known of building on this type of site, but much could be learned from a research study.

Similar detailed local studies must be made of the performance of roads, airports, and ordinary buildings which have to be built on permafrost, but this type of investigation is perhaps the most obvious of all desirable permafrost research so that it need be no more than mentioned. What is not so obvious is the research necessary into the effect upon permafrost of unusually large structures, especially those which expose much metal, such as steel towers, and which therefore act as collectors for solar radiation. An interesting theoretical approach to this problem has been made by Nees (1952).

No detailed investigations of engineering problems can proceed very far without the necessity for accurate data (or assumptions, in the absence of data) on the physical and mechanical properties of frozen soils of varied types. Some work has been done, but so far this has only been enough to show the need for extensive laboratory and field research into the many complex aspects of this matter (Hardy and D'Appolonia, 1946). Fortunately, such investigations should serve a dual purpose as much should be learned at the same time about the mineralogy of these soils and so about their geological origin and history. Of even greater interest, however, will be the search for an explanation as to how the soil became frozen. Many samples of soils in permafrost, for example, have a phenomenally high water content and a structure rarely encountered in normal soils today.

This, in turn, leads to the greatest question of all in relation to permafrost. Is it merely the cumulative result of successive winter seasons or is it a relic of the last ice age, or is it partly recent and partly relic? There are some who have already formed their own conclusions on this question. There are others (of whom the writer is one) who still have open minds on the subject and who will, therefore, welcome all research work which may throw some light on this unusually significant matter.

It is probable that all approaches to this question will have to be very long-term in character. Fortunately a start has been made at one approach by the installation of sensitive temperature-measuring devices in at least two very deep holes in the Arctic. One of these is a United States venture at

[1] *See* paper by H. R. Joesting in this volume.

Point Barrow, Alaska (MacCarthy, 1952) and the other Canadian at Resolute Bay, Cornwallis Island (Thomson and Bremner, 1952). Results so far obtained show that the ground is below 0°C at both locations to a depth considerably in excess of 1,000 feet. If arrangements can be assured for the maintenance of accurate temperature records over a long term of years from these and many similar holes which may be instrumented, the puzzle of the character of permafrost may one day be solved.

Finally, reference must be made to Russian work and to the striking similarity that must exist between the permafrost problems of North America and those of the U.S.S.R. Early Russian studies were pioneer steps in this field of applied scientific research, and their publications of the 'thirties show clearly how far advanced permafrost studies in the U.S.S.R. were even at that time. It is known that this early Russian work has been continued and extended and a Permafrost Research Institute established, but few recent Soviet publications on permafrost have become available in North America. It is greatly to be hoped that in the future information on this strictly factual and scientific subject will be freely exchanged between the U.S.S.R. and North America.

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GEOPHYSICAL RESEARCH IN ALASKA

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SEVERAL fields of geophysical research depend for basic data upon observations of geodesy, which treats of the size and the shape of the earth. The following account describes the status of the geodetic network, of observations in the fields of gravity, geomagnetism, radio propagation, and seismology in Alaska, and suggests some problems of further study and research.

Geodesy

Observations over first order arcs of triangulation are adjusted by use of conditioning equations to provide a horizontal datum plane of reference. The adjustment of lines of precise level furnishes fixed elevations above the datum of sea level. The latter is determined by tidal observation at the sea coast over a period of years. Astronomical and gravity observations complete the data necessary to coordinate the network of meridians and parallels and points of precise elevations which are necessary for the delineation of surface characteristics and the determination of the geoid. In both the United States and Canada geodetic surveys are a government responsibility.

In Alaska the Coast and Geodetic Survey has made triangulation surveys along the entire coastal area. A continuous scheme of triangulation extends from the British Columbia–Alaska boundary through southeastern and southwestern Alaska, to the western extremity of the Aleutian Islands; by connection with the Alaska Peninsula, along the shoreline and on the islands of the Bering Sea to Bering Strait, the Arctic Ocean, and Point Barrow; thence along the northern shore of Alaska to the 141st meridian, where a junction is made with the survey of the International Boundary Commission. The latter triangulation completes the geodetic network around the periphery of Alaska. A connection has been made with the geodetic network of Canada in southeastern Alaska and on the Alaska Highway. In the interior, connecting loops exist over the areas adjacent to the Alaska Railroad, Richardson Highway, Glenn Highway, Tok Cutoff, Steese Highway, Yukon River from Tanana to St. Michael, Holitna River, Kuskokwim River, and east of Kotzebue Sound. Recently, arcs of triangulation have been extended from Fairbanks to Umiat, west to the Bering Sea shores and north to the arctic coast at the mouth of the Colville River; from Tanana to the Porcupine River, thence upstream to the

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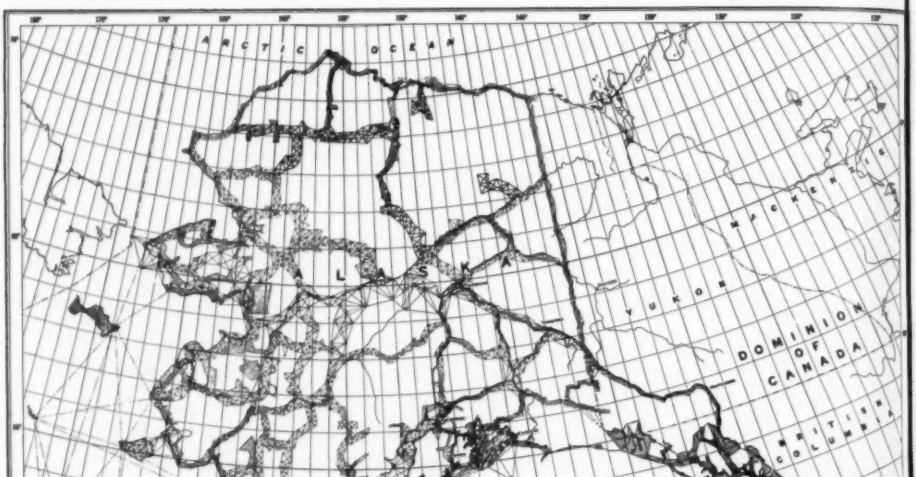

Fig. 1. Geodetic control in Alaska.

Alaska–Yukon Boundary. In addition to the main geodetic scheme, the Geological Survey and the Corps of Engineers have carried out triangulation projects for the preparation of topographical maps.

The elevations of established bench marks above mean sea level have been determined by lines of precise levels on the Alaska Highway from Whitehorse to Fairbanks, on the Richardson Highway from Fairbanks to Valdez and Chitina, on the Glenn Highway and the Tok Cutoff, and on the Steese Highway from Fairbanks to Circle, also from Haines over the Haines Cutoff. The long-range program contemplates levelling on the new highway from Paxson on the Richardson Highway to Cantwell on the Alaska Railroad; from Fairbanks to Livengood, and from Livengood to Eureka, thence to Manley Hotsprings, and downstream on the Yukon River to Kaltag, and thence to Unalakleet and St. Michael on the Bering Sea coast, where connections will be made to tidal bench marks.

The determination of the value of gravity at selected intervals for studies of the figure of the earth is one important phase of geodetic operations. In Alaska the immediate purpose of the gravimetric program of the Coast and

Geodetic Survey is first to establish a system of gravity bases, and then a regional pattern of gravity stations determined with the gravimeter. The plan is to obtain sufficient gravity detail in one or more areas that gravimetric deflections of the vertical can be determined. These deflections, combined with astronomic-geodetic information referred to the North American 1927 datum, should produce valuable data for future determinations of the figure of the earth.

Another phase of this work is the basic coverage of gravity determinations for use in geophysical prospecting. Normally the value of gravity varies according to latitude and elevation. Any anomalous value indicates divergences which may probably be attributed to changes in the consistency of the earth's crust. Investigation of areas where anomalies occur may lead to the discovery of metallic ores or oil-bearing strata.

Gravity bases were recently determined by pendulum apparatus at Point Barrow, Umiat, Fairbanks, Anchorage, and Kodiak. Seventeen pendulum stations have been established between 1897 and 1952, and cover a latitude range from the 58th parallel to Point Barrow. Combined with the gravity pendulum project along the Alaska Highway the necessary basic control will be provided for more extensive gravimetric coverage. The ultimate goal is an area-breakdown of gravity determinations using gravimeters calibrated with reference to the basic gravity pendulum stations.

Future work

Considering the vast unmapped areas of arctic North America, it is essential that the programs initiated by the United States and Canada continue and, if possible, be accelerated in the interest of geophysical research. In Alaska, the long-range program calls for the extension of these surveys in the large area between the Yukon River and the Arctic Ocean, and for a gradual breakdown by means of closer spacing of arcs of triangulation to form a continuous geodetic network with all survey monuments interrelated. The program for shoran photogrammetry will extend knowledge of basic features of this area for topographical maps, for geological surveys, and for further detailed research.

Among the many problems in the Arctic of concern to the geodesist, the following may be listed:

1. Stability of survey marks. What is the best type of monument to set in various types of soil in the Arctic so as to ensure that the survey point will be stable in position both horizontally and vertically? There is already a limited amount of information available, but research with a definite program over a period of years is needed.

2. Vertical land movements. The relationship of mean sea level to surrounding land areas at the head of Lynn Canal has changed over a period of years. Are similar changes occurring at other places in the Arctic and Subarctic? Is the land rising, or the sea falling?

3. Horizontal land movements. In the regions of pronounced seismic activity in Alaska are movements occurring similar to those in California?

Seismologists and geologists can perhaps tell the geodesist of regions susceptible to such movements so that a program of visual observations over a period of years may be initiated.

4. Heights of mountains. Elevations of Mount McKinley recently determined show an increase over earlier determinations. Is this increase due to greater deposition of snow on the peak, to greater precision in the measurements, or is it a real increase?

Geomagnetism

Geomagnetic data in Alaska have been gathered for many years by the Coast and Geodetic Survey. The work began with scattered observations by field parties in those areas most accessible to water routes, and by the establishment of the magnetic observatory at Sitka at the turn of the century. The present activities include the operation of magnetic observatories at Sitka, College, and Point Barrow; a network of repeat stations where observations are made at intervals of five years; broad regional surveys by airborne instruments; and steady accumulation of observations obtained by field parties primarily concerned with other phases of the Survey's activities.

Scientifically, the most important part of the magnetic work is that carried out at the laboratories, where highly trained observers maintain virtually unbroken recordings of changes in direction and intensity of the earth's magnetic field, and carry out frequent observations with absolute instruments. The repeat data are of importance in filling in the patterns of secular change; these stations are usually placed at sites convenient to air transport. The airborne surveys at high levels provide vital facts on the general patterns of distribution of the permanent field over vast interior and offshore areas, which cannot be adequately surveyed by older methods except at tremendous cost. Incidental magnetic data accruing from other survey field operations contribute to knowledge of local magnetic conditions in coastal waters where frequent occurrence of magnetic irregularity offers a potential menace to safety at sea.

One reason for special interest in Alaskan magnetic work lies in the fact that the Territory is nearly bisected by the auroral zone, and is ideally situated for a chain of magnetic observatories extending north and south of that zone. Valuable data on the pattern of magnetic storms and associated phenomena are being provided by the Sitka, College, and Point Barrow magnetic observatories.

Future work

It is clear that the relations of geomagnetic work to navigation, land surveying, radio propagation work, and geological investigations are all of such a nature as to stimulate and justify a sustained and expanded program in this vital field of science.

The following are some of the problems on which future work is needed:

1. The riddle of the elongated pattern of the permanent field northwest of the known magnetic pole.

2. The behaviour of the auroral zone, especially during times of enhanced magnetic activity.

3. The development of procedures for forecasting the various kinds of solar and terrestrial activity that pertain to magnetism and to the use of radio facilities.

4. Increased understanding of daily magnetic variations, particularly with a view to eliminating the effects of various transient fluctuations from magnetic survey data, so that they may be of maximum benefit in geophysical and technological applications.

Some of these problems are currently being studied at the Geophysical Institute of the University of Alaska, and others at various establishments in the world centres of scientific study. There is need for closer spacing of repeat stations to delineate more accurately the location of isomagnetic lines in the northern area and to give basic data for comparison with airborne magnetic surveys and geophysical prospecting investigations.

Ionosphere studies

A study of radio wave propagation in the Arctic is part of an extensive research program of the Central Radio Propagation Laboratory of the National Bureau of Standards. The laboratory either operates, or has supplied equipment for the operation of eight arctic field stations to make regular soundings of the ionosphere at vertical incidence. Three of these are in Alaska (Point Barrow, College, and Anchorage), two are in Canada (Resolute Bay and Baker Lake), two are in Greenland (Godhavn and Narsarssuaq), and one is in Iceland (Rekjavik). The laboratory receives the data from these stations and is also provided with tabulations of hourly measurements made at each of nine other foreign arctic stations.

The observations at these stations give a measure of the electron density in the ionosphere. The variations of electron density with height, and the variations with time of day, season, and solar activity are of great theoretical interest and also of practical importance in studies aimed at improving radio communication in the Arctic. At College regular auroral observations are made, which include measurements of height and brightness. The radio data, when combined with these observations, not only add to the understanding of the relatively modern problems of radio wave propagation but should also aid in the solution of the ancient riddle of the Aurora Borealis.

The importance of these arctic studies by the National Bureau of Standards cannot be over-emphasized. Since radio gives the only possible means of communication over much of the vast area, any improvement in radio communication is extremely valuable. In addition, theoretical investigations of the arctic upper atmosphere may lead eventually to a better understanding of the physical world.

Seismology

Alaska is in general an area of only moderate seismological activity, but with important exceptions. The Aleutian Islands, the Alaska Peninsula, the

southern half of central Alaska, and southeastern Alaska are all marked by major activity. The areas are part of the major tectonic formation known as the circum-Pacific earthquake belt, the most extensive of all such belts. It is characterized everywhere by young and growing mountains on land and by deep parallel trench formations off the coasts. In 1899 at Yakutat, near the eastern end of this belt, one of the greatest known earthquakes occurred, which shifted the shore rocks vertically by as much as 47 feet. In the trench southeast of Unimak Pass, in 1946, a submarine quake caused the sea bottom to rise initiating a seismic wave that destroyed the lighthouse at Scotch Cap with the loss of several lives, and then travelled across the deep Pacific Ocean to kill 173 people and destroy $25 million worth of shore property at Hawaii.

Seismographs are operated at the Sitka and College geomagnetic observatories of the Coast and Geodetic Survey in Alaska. These stations and others outside Alaska provide the data needed to detect and locate the more important earthquakes originating in Alaska, to outline the various zones of seismic activity in the region, and to ascertain the degree of earthquake hazard in each. This information is of special value to engineers designing important structures, and to insurance companies needing statistical information on which to base earthquake insurance rates. Seismological techniques are also of value to geophysical prospectors.

Future work

Because the transmission and changing velocities of different types of seismic waves over various paths through the earth's interior can be calculated from seismographical data, significant deductions can be made regarding the structural and physical state of the interior of the earth. Additional seismological stations should be located in non-active areas in the north and along the arctic coast for this study.

GEOPHYSICAL EXPLORATION IN ALASKA*

H. R. Joesting†

In all parts of the world, geophysical exploration is concerned with the composition, form, and structure of the crustal rocks, with the search for minerals, mineral fuels, and ground water, and with problems of civil engineering and construction. In Alaska it is also concerned with permafrost, which has a marked modifying effect on the properties and distribution of near-surface materials, especially of unconsolidated deposits. Permafrost can usually be identified and mapped by geophysical methods, and it has therefore become a major field for geophysical investigation in Alaska.

In this paper I have attempted to review geophysical investigations in Alaska of geologic and related problems and to indicate problems worthy of future investigation. The earlier investigations are emphasized because relatively little information on them has been published. Permafrost investigations are also emphasized because of their importance in cold regions. Conversely, the recent extensive petroleum explorations in northern Alaska are treated more briefly than their importance might seem to warrant, because they are generally similar to petroleum explorations in other regions. In some instances it has been necessary to distinguish rather arbitrarily between geologic and geophysical endeavours, which are usually complementary. The paper is not intended to be exhaustive or complete, and discussions of investigations in fields of geophysics not closely related to geology have been omitted.

Permafrost and related problems

The earliest systematic attempts to use geophysical methods in interior Alaska were apparently all made by the U.S. Smelting, Refining, and Mining Company in the Fairbanks district. In 1928 magnetic surveys were carried out under the direction of E. E. Maillot, assisted by J. C. Boswell,[1] to determine their usefulness in tracing buried gold placer channels. The gold occurs on or near bedrock in gravels covered by as much as 200 feet of silt and muck. (Muck is dark-coloured silt, high in organic and water content and is usually frozen). Boswell concluded that the placers investigated did not contain sufficient magnetic black sands to affect a field balance.

*Publication authorized by the Director of the U.S. Geological Survey.

†Staff Geophysicist, U.S. Geological Survey.

[1]Boswell, J. C. 1929. "Application of geomagnetics to placer exploration". Unpublished thesis for B.S. in Mining and Geology, University of Alaska.

In 1933 the same company, using electrical resistivity and potential-drop-ratio methods, made systematic efforts to outline areas of permafrost and determine thickness of unconsolidated material over bedrock. On the whole these tests were not successful,[1] possibly because of the complex stratigraphy and permafrost relations of the partly frozen overburden.

In the summer of 1938 experimental seismic refraction surveys were made under the direction of L. D. Leet and H. G. Taylor for the same company. On the basis of this work, Taylor[2] concluded that the schist bedrock underlying the frozen muck and gravel in the Fairbanks district could not be mapped, because seismic velocities in frozen gravel were almost as high as in bedrock. Bedrock under frozen muck usually could not be mapped, because of variations in velocities in both bedrock and overburden, the latter resulting from thawed spots. Difficulty was generally experienced in determining depths to bedrock and to top of gravel in areas of discontinuous permafrost because of complex velocity relationships. In thawed areas it was usually possible to determine thickness of muck and gravel overlying the schist bedrock, though the accuracy was low in areas of deeply weathered bedrock. Considerable information was obtained on velocities of propagation in the formations in the Fairbanks district, and the following figures were recorded:

Light muck	1,000– 1,650 f.p.s.
Thawed muck	1,800– 4,000
Frozen muck	4,250–10,000
Thawed gravel	2,000–10,000
Frozen gravel	13,000–15,250
Bedrock (schist)	7,500–20,000

Light muck is evidently unfrozen, tan-coloured silt of aeolian origin (Tuck, 1940, pp. 1,299–306).

The rather wide variations in these velocities may have resulted in part from the discontinuous nature of permafrost in much of the Fairbanks district, so that measurements in completely frozen or completely thawed material were not always possible. Thus the lower velocity given for frozen muck (4,250 f.p.s.) may actually be for muck that was largely thawed, and the higher velocity for thawed gravel (10,000 f.p.s.) may result from an "island" of permafrost in otherwise thawed material. It is also likely that the higher velocity recorded for bedrock (20,000 f.p.s.) may result in part from irregularities of the surface of bedrock as well as from complex permafrost conditions.

In spite of the wide variations, Taylor's figures indicate that the velocities in frozen material are in general higher than in their thawed counterparts. This is substantiated by results obtained later in northern Alaska,[3] where velocities in continuous permafrost range between 8,000 f.p.s. in frozen

[1]Crawford, J. R. and E. E. Maillot. 1954. Personal communications.

[2]Taylor, H. G. 1939. "Report on geophysical work by the seismic method in the placer deposits of the Fairbanks district of Alaska". In files of U.S. Smelting, Refining, and Mining Company.

[3]Unpublished reports of United Geophysical Company to Director of Naval Petroleum and Oil Shale Reserves, 1950.

alluvium and 13,500 f.p.s. in frozen Tertiary sediments. The vertical velocities in northern Alaska were slowest and the velocity increased as the travel path approached the horizontal. Barnes[1] found horizontal velocities in frozen alluvium in the Fairbanks district to be comparatively high—of the order of 7,000 to 13,000 f.p.s. He states that a high seismic velocity is an almost sure indication of frozen ground (alluvium) and can only be misinterpreted as bedrock. He also noted that frozen alluvium is markedly anisotropic to the propagation of seismic waves.

Other experimental work includes the studies made by Matthews[2] in 1937 to test the use of the electrical resistivity method in exploring for gold placers in the Fairbanks district, and the more comprehensive investigation by the Territorial Department of Mines during 1938 to 1940 of magnetic and resistivity methods as aids to prospecting, mining, and geologic investigations in interior Alaska (Joesting, 1941). Magnetic surveys were found to be useful in prospecting for buried gold placers under favourable conditions, that is where moderate to large amounts of magnetic black sands were concentrated with the gold in comparatively shallow pay streaks, and where the effects of the black sands were not masked by bedrock anomalies. *In situ* determinations of resistivities of unconsolidated and consolidated rocks in the Fairbanks, Livengood, and Circle districts showed that in general the resistivities of frozen rocks are considerably higher than of comparable thawed materials and that these differences are sufficient to indicate the extent and approximate thickness of frozen unconsolidated deposits. Determinations of depth to bedrock were possible under favourable circumstances but were generally unsatisfactory in areas of discontinuous permafrost. It was also found that the contrast in resistivities between frozen and thawed unconsolidated deposits could facilitate the search for ground water.

In 1944 a brief study of the application of geophysical methods to permafrost problems was made by the U.S. Bureau of Mines and the Corps of Engineers, U.S. Army. Shallow resistivity surveys were made at Northway on the upper Tanana River, at Wolf Creek in the Fairbanks district, and at Galena on the Yukon River; and one seismic refraction station was occupied at Northway. On the basis of these surveys Swartz and Shepard[3] concluded that the top of the permafrost can usually be determined by both resistivity and seismic methods, and that areas of thawed and frozen ground can likewise be mapped by both methods. They also concluded tentatively that the bottom of the permafrost can be determined by resistivity, but not by seismic refraction because of unfavourable velocity ratios, and that ice lenses could be indicated by resistivity.

[1]Barnes, David F. 1954. "Preliminary report on tests of application of geophysical methods to arctic ground-water problems". Unpublished report in files of U.S. Geological Survey.

[2]Matthews, Ted C. 1938. "Application of geo-resistivity to placer exploration". Unpublished thesis for Batchelor of Mining Engineering, University of Alaska.

[3]Swartz, J. H. and E. R. Shepard. 1946. "Report on a preliminary investigation of the possible application of geophysical methods to studies of permafrost problems in Alaska". Unpublished report in files of U.S. Geological Survey.

More extensive experimental resistivity surveys were made in the Fairbanks district in 1948 by the U.S. Geological Survey under the direction of J. H. Swartz. This work substantiated earlier conclusions concerning the use of resistivity in permafrost areas, and the data are being incorporated in a report in preparation. In 1952 the Survey made an evaluation of electrical and seismic methods in the search for ground water in permafrost areas at the request of the Engineer Research and Development Laboratory, Corps of Engineers.[1] Following recommendations in this report, further surveys were made during the summer and fall of 1952. The geophysical work was coordinated with physiographic and ground-water studies and with a limited amount of drilling.

During the summer of 1953 experimental surveys were made by the U.S. Air Force Cambridge Research Center to determine the thickness of permafrost by measuring the frequency dispersion of flexural waves propagated through the permafrost layer. These experiments were made in continuous permafrost in the Farmers Loop area near Fairbanks. According to Hansen[2] records of flexural waves were obtained at distances of 3,000 feet to several miles using large charges placed in the permafrost. The method is based on one used by Press *et al.* (1951) to measure the thickness of sea ice.

Seismic reflection and gravity surveys were made in 1951 by Allen and Smith (1953) on the Malaspina Glacier, northwest of Yakutat Bay, to determine ice thickness and configuration of the subglacial floor. The information was obtained to aid in the study of structural relationships and flow within the glacier. Seismic refraction and gravity profiles were also run in 1952 on the Juneau Ice Field in southeast Alaska in connection with glaciological studies and to determine ice thickness (Miller, 1953a).

Geothermal investigations

In 1949 long-term geothermal studies were initiated in northern Alaska by the U.S. Geological Survey with the support of the Office of Naval Research and the Bureau of Yards and Docks of the Department of the Navy, and later of the Snow, Ice and Permafrost Research Establishment of the Corps of Engineers. These studies, which are still underway, aim to determine the temperatures and thermal properties of perennially frozen and other sub-surface materials in arctic Alaska and to relate them to the geology. Precise measurements of temperature have been made in both deep and shallow holes, most of them drilled in exploring for oil, and thermal conductivity measurements have been made of near-surface materials. The work has been coordinated with the extensive exploration program of the Office of Naval Petroleum and Oil Shale Reserves; the geothermal studies were in fact made feasible by the exploration program (MacCarthy, 1951, 1952).

[1]MacCarthy, Gerald R. and others. 1952. "Geophysical methods of prospecting for ground water in permafrost regions". Unpublished report in files of U.S. Geological Survey.

[2]Hansen, Roy E. 1954. Personal communication.

Temperature measurements in shallow boreholes have also been taken in the Umiat area of northern Alaska by a group from Boston University and in the Fairbanks district by the U.S. Geological Survey and the Corps of Engineers. Other temperature measurements were made in the boreholes in the Juneau Ice Field in southeastern Alaska in connection with glaciological studies (Miller, 1953b).

Sedimentary geology and oil exploration

During the period 1944 to 1953 extensive geophysical surveys were carried out in Naval Petroleum Reserve No. 4 and in much of the rest of northern Alaska on behalf of the Office of Naval Petroleum and Oil Shale Reserves of the Navy Department. Included were regional gravimetric surveys over much of the reserve, seismic reflection and refraction surveys in selected areas by the United Geophysical Company, aeromagnetic surveys of most of the reserve and the area eastward to Flaxman Island by the U.S. Geological Survey, and smaller-scale gravimetric surveys during 1945 by the Bureau of Yards and Docks. These have been discussed in reports by the United Geophysical Company[1] and Payne and others (1951). Additional reports and technical data are available for public inspection in the offices of the U.S. Geological Survey in Washington and the Inspector, Naval Petroleum Reserve, Fairbanks, Alaska.

These large-scale investigations exceed in magnitude the combined total of geophysical exploration already carried out in the remainder of Alaska. They were coordinated with extensive geologic investigations and by considerable test drilling. They were preceded by geologic and other explorations in northern Alaska, largely by the U.S. Geological Survey, over a period of many years, and conditions favourable to the occurrence of petroleum had been indicated by Smith and Mertie (1930), Smith (1939), and Ebbley and Joesting.[2]

As a result of the combined investigations it has been established that the region north of the Brooks Range is a single asymmetric sedimentary basin with its axis parallel to the range. Its deepest part is apparently within the foothills province of the region and not near the coast of the Arctic Ocean as was previously supposed. This sedimentary basin has been broadly defined, and a band of folding at least 30 to 50 miles wide and extending east more than 250 miles across the central part of the reserve has been outlined. In addition several anticlinal folds were examined in detail by seismic methods, especially along the northern part of the folded zone where exposures are insufficient to permit surface mapping of geologic structure (United Geophysical Company, 1954, *see* footnote 1, below); Gates, 1953; Gryc, Miller, and Payne, 1951).

[1]United Geophysical Company. 1954. "Final report on geophysical exploration of Naval Petroleum Reserve No. 4 and adjoining areas of Alaska, 1945 to 1953". Official report to Director, Naval Petroleum Reserve.

[2]Ebbley, Norman, Jr. and H. R. Joesting. 1943. "Report of investigation of petroleum seepages, Arctic Slope area, Alaska". Unpublished report in files of U.S. Bureau of Mines.

Renewed interest has been shown by private concerns in the oil resources of southern and southwestern Alaska during the past few years. In this connection seismic surveys were carried out on the Kenai Peninsula north of Homer during 1954 in areas where exposures of consolidated rocks are scarce.

In addition, the recent discovery of marine fossils in interior Alaska points up the possibility that other parts of the Territory may also contain oil (Payne, 1953; Péwé, 1954). The fossils were found in basal Quaternary deposits near Fairbanks, at the north edge of the middle Tanana basin. They are believed to have been derived from marine Tertiary rocks deposited in the Yukon–Tanana plateau region and removed during the Pliocene uplift, according to Payne. Payne further points out that under favourable conditions marine Tertiary rocks might be preserved in the middle Tanana basin and also in other basins in Alaska. Such rocks would be potential sources of petroleum, especially if considerable thicknesses are present.

Reconnaissance aeromagnetic surveys were flown by the U.S. Geological Survey in several parts of Alaska during 1954 to gain information on the approximate thickness of sedimentary rocks in the basins and also on regional structural trends and buried intrusive rocks. Among the areas flown over were parts of the Koyukuk geosyncline and of the Bethel, Nushagak River, Cook Inlet, Copper River, Yukon Flats, and Tanana River basins.

Metalliferous lodes

The first use of geophysical methods in prospecting for metalliferous lode deposits in Alaska was probably in 1930, by the Schlumberger Geophysical Company. The work was done at the Fidalgo-Alaska mine, on Prince William Sound south of Valdez. The problem was to find additional deposits of chalcopyrite and pyrite, or to extend known deposits. Spontaneous potential, equipotential, and electrical resistivity methods were used and several conducting zones were outlined that may have been related to deposits of sulfide minerals, but no commercial deposits are known to have been found.

No other geophysical prospecting for lode deposits seems to have been done until the period 1941 to 1943, when the Territorial Department of Mines carried out magnetic surveys for tungsten deposits in the Fairbanks district[1] (Joesting, 1943, p. 22), and for chromite deposits at Claim Point on the Kenai Peninsula.[2] Additional geophysical work in 1952 by the Territorial Department of Mines in the Lost River area of the Seward Peninsula, attempted to locate tin-bearing granite cupolas in limestone by use of magnetic and electrical resistivity methods. Negative results were obtained, partly because

[1]Joesting, H. R. and Eskil Anderson. 1941. "Preliminary report on scheelite deposits in the Fairbanks district, Alaska". Unpublished report available for public inspection at Office of Commissioner of Mines, Juneau, Alaska.

[2]Joesting, H. R. 1943. "Geologic and magnetic survey of chromite deposits, Claim Point, Alaska". Unpublished report available for public inspection at Office of Commissioner of Mines, Juneau, Alaska.

of the disturbing effect of permafrost, and of buildings and mining equipment.[1] Reconnaissance magnetic surveys were flown in the tin-bearing areas of Seward Peninsula in 1954, but attempts to locate granite cupolas were again unsuccessful. In the summer of 1954 an electromagnetic survey was made by private interests of the chalcopyrite and pyrite deposits at Horseshoe Bay on Latouche Island, Prince William Sound. Favourable results were reported (Territorial Dept. of Mines, 1954).

A number of dip-needle and magnetic-declination surveys for magnetic iron deposits were made in southeastern Alaska during the period 1942 to 1944. Records are available of surveys in several localities on Prince of Wales Island: on the Kasaan Peninsula (Erickson, 1948, p. 4), in Jumbo basin (Wright and Fosse, 1946, p. 6; Kennedy, 1953, pp. 36–8), and in the Mt. Andrew area.[2]

Several aeromagnetic surveys have also been made in connection with prospecting for metallic minerals. Among those in southeastern Alaska are a survey by the U.S. Geological Survey of southern Prince of Wales Island to obtain geologic information in an area containing deposits of magnetite and associated copper minerals,[3] and surveys by private interests of parts of the Mansfield Peninsula for nickeliferous deposits and of the Snettisham area for magnetic iron deposits.[4]

A reconnaissance aeromagnetic survey was flown in 1954 by the U.S. Geological Survey in the Snag River area, north of the Nutzotin Mountains, to relate magnetic and geologic features and to determine the magnetic effect of a mineralized zone that had been mapped in the adjoining area in Canada.

Radioactive minerals

Reconnaissance surveys for deposits of radioactive minerals have been made during recent years in many parts of Alaska both on foot, by car, and by aircraft using Geiger and scintillation counters. Most of these investigations have been made by the U.S. Geological Survey; their scope is indicated in publications by Gault *et al.* (1953), Moxham and Nelson (1952), Wedow,[5] and Wedow and others (1953).

Other investigations have been made by the Territorial Department of Mines, and recently there has been increasing activity by prospectors.

[1]Williams, J. A. and R. H. Saunders. 1953. "Geophysical exploration at the Lost River tin deposit, Alaska". Unpublished report available for public inspection at Office of Commissioner of Mines, Juneau, Alaska.

[2]Goddard, E. N., L. A. Warner and Matt Walton. 1944. "The copper-bearing iron deposits of the Mt. Andrew–Mamie area, Alaska". Unpublished report available for inspection in office of U.S. Geological Survey, Washington, D.C.

[3]Henderson, John, and others. 1954. "Aeromagnetic map of the southern part of Prince of Wales Island, Alaska". Open-file map available at offices of U.S. Geological Survey in Washington, D.C., Los Angeles, Menlo Park, San Francisco, and Denver, and in Anchorage, College, and Juneau in Alaska.

[4]Holdsworth, Phil. R. 1954. Personal communication.

[5]Wedow, Helmuth, Jr. 1951. "Adaptation of portable survey meters for airborne reconnaissance with light planes in Alaska". U.S. Geological Survey TEMR 323, released by Technical Information Service, U.S. Atomic Energy Commission, Oak Ridge, Tenn.

Additional airborne surveys were made in 1954 by the U.S. Geological Survey in the following areas: Buckland–Kiwalik, Nixon Fork, Tyonek, Yakataga Beach, and Nutzotin (Snag River).

Volcano research

A program of volcanological research in the Aleutian Islands was prompted by the eruption in June 1945 of Okmok volcano near Fort Glenn on Umnak Island. Geologic and geophysical investigations were started by the U.S. Geological Survey in 1946 at the request of the War Department. The geophysical investigations, which were terminated in 1954, were supported jointly by the Office of Naval Research and the U.S. Geological Survey (Swartz, 1951).

In connection with the geophysical investigations seismographs were set up on Adak and Great Sitkin islands to record earthquakes related to volcanic activity in the Aleutian Islands and tectonic activity in the Aleutian Trench. Measurements of earth tilt and of changes in the earth's magnetic and electrical fields were also made near Great Sitkin volcano.

Problems for future investigation

Except for problems related to permafrost, problems of geophysical exploration in Alaska are generally comparable to those in the western United States and western Canada. As these problems are practically infinite in number and variety, this discussion is restricted to those that appeal to me as interesting and important.

Permafrost

Permafrost—its distribution, physical properties, and origin; its relation to climate, vegetation, and animal life; and its effect on human activities—remains a field for investigation of first importance in northern regions, and one that has been pursued more assiduously in the U.S.S.R. than in Alaska. Geophysical methods, usually in combination with other methods of investigation, provide an effective means of adding to our knowledge of the distribution, physical properties, and origin of permafrost.

The distribution and upper surface of permafrost, for example, can now ordinarily be determined rapidly by electrical resistivity and seismic refraction surveys, supplemented by drilling and temperature measurements. The lower surface of permafrost may also be defined by resistivity, provided the frozen and thawed materials occur in suitably uniform, horizontal layers. Such ideal conditions are seldom found in nature, however, consequently the development of better means of obtaining and interpreting resistivity data in terms of depths to the bottom of permafrost is highly desirable. Seismic refraction methods are usually not suitable for defining the lower surface of permafrost, because unfavourable velocity relationships usually exist between permafrost and the underlying thawed material, especially where the thawed material is unconsolidated. Seismic reflection methods in theory do not have this limitation. Successful tests of shallow reflection

equipment have recently been made by the U.S. Geological Survey (Pakiser and Mabey, 1954; Pakiser, Mabey, and Warrick, 1954) and this equipment may eventually be useful in defining the lower boundaries of permafrost.

Information on the decay or growth of permafrost and of heat flow from the earth can be gained from measurements of thermal conductivities and temperatures. Precise temperature measurements in boreholes could also conceivably be used to give information on climatic changes during the fairly recent past. In this connection Henderson[1] has computed the effect of a temperature increase of 10°C at the surface, assuming that changes as small as 0.005°C per year or 0.05°C per 10 years can be measured (this is about the limit of present-day equipment). Using reasonable values for thermal diffusivity, on which depends the rate of propagation of a thermal wave, it was found that such a wave could not be detected later than 490 years after it started from the surface. The maximum detectable depth of penetration would be about 800 feet after the lapse of 300 years, if the diffusivity were 0.01, and 1,100 feet after 300 years if it were 0.02. The simplifying assumption of a step-function temperature increase doubtless gives values somewhat greater than would be found experimentally. Field laws governing thermal processes in permafrost have been developed by Redozubov (1946).

More quantitative information on the physical properties of perennially frozen materials, their interrelationships, and their dependence on such factors as temperature, porosity, and permeability is required as a basis for an adequate understanding of permafrost. Electrical, elastic, and probably thermal properties are markedly affected by temperature. Ananian (1945), Dostovalov (1947), and others in the U.S.S.R. have shown that the resistivity and dielectric constant of perennially frozen materials depend on temperature as well as on other factors, but no quantitative investigations along these lines have yet been made in Alaska.

Adaptation or development of geophysical equipment for use in low temperatures is also desirable, especially as winter is the most favourable season for surface travel in many parts of Alaska. Adaptation of electrical resistivity equipment would require, for example, improved means of generating electrical power, of introducing current into the frozen ground, and of measuring current and potentials, and an insulation that would remain flexible. Development of electromagnetic induction equipment would probably also be worthwhile, as it would eliminate many of the practical difficulties of using electrodes in contact with the frozen surface and would permit more rapid mapping of permafrost. Weasel-mounted equipment could doubtless be developed for continuous cross-country traverses during the winter. Inductive methods have apparently been used to a considerable extent by the Russians in permafrost studies (Petrovsky, 1947; Petrovsky and Dostovalov, 1947 a,b) but little information is available on recent results.

Russian investigators have also noted spontaneous electrical currents at the interface between the thawed active layer and the permafrost layer

[1]Henderson, R. G. 1954. Personal communication.

(Kozin, 1936; Enenstein, 1947). Casual observations have failed to corroborate this phenomenon in Alaska. Systematic studies under known conditions would be worthwhile.

Sedimentary basins and oil exploration

If the Copper River region, Tanana River, Yukon Flats, and similar regions in Alaska prove to be basins of marine deposition as well as physiographic basins, they would become of great interest as potential sources of oil, and intensive geologic and geophysical investigations would be warranted. Such investigations would initially be concerned mainly with stratigraphic and structural relationships and would follow the same general pattern as in other parts of the world. It is probable, though, that airborne surveys would be used to a greater extent, at least in the initial stages of exploration, because of difficulties of surface travel.

Effect of earth's crust on terrestrial magnetism and electricity

In connection with the International Geophysical Year of 1957 to 1958, during which simultaneous observations will be made in many parts of the world of geophysical phenomena such as cosmic radiation, the aurora, geomagnetism, and ionospheric activity, it would seem desirable to carry out a series of magnetic and electrical investigations in which the modifying effects of the earth's crustal rocks are taken into account. More specifically, these should be concerned with the effects on the earth's magnetic and electrical fields, especially during periods of magnetic and auroral disturbance, of spatial variations in the magnetic and electrical properties of the crustal rocks due to differences in their structure and composition. These investigations should preferably be made in areas of high auroral activity, such as the Fairbanks district.

A start along these lines was made in Canada by Morley (1953), who measured two simultaneously operated stations, placed initially 130 miles apart and later 87 miles apart, during periods of severe magnetic disturbance. No attempt was made, however, to compare the amplitude of the disturbances with the magnetic susceptibility of the underlying rocks.

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PROBLEMS OF GEOPHYSICS IN THE CANADIAN ARCTIC

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APART from upper atmospheric studies, which are being dealt with in the chapter on meteorology, the main Canadian contributions to geophysics in the Arctic have been made in the fields of terrestrial magnetism, gravity, and seismology. Systematic programs of observation have already been initiated in these three fields, and are likely to be expanded in time. Those observations which have been made up to the present, together with some arctic problems for future study, are considered briefly in this article. Meteors, meteorites, and meteorite craters are also discussed because of their geophysical as well as astronomical implications.

Geomagnetism. By R. G. Madill

Arctic North America, containing the north magnetic pole and much of the auroral zone, offers opportunities for research on the earth's magnetic field at high magnetic latitudes which can only be equalled in the far less accessible Antarctic. It is an area where the magnetic declination, or variation, of the compass changes through 360 degrees, the inclination, or dip, reaches its maximum of 90 degrees, and the horizontal force decreases to zero. It is here that changes in the direction and magnitude of the horizontal field reach their greatest values from hour to hour and year to year. It is here, also, that magnetic disturbances are almost continuous along the auroral zone which expands during severe magnetic storms, and seriously affects the magnetic field far south of the Arctic.

The earliest magnetic observations in extreme northern latitudes were made by scientists and navigators during voyages of discovery, particularly in connection with the search for a Northwest Passage, and the attempts to rescue the Franklin expedition (Kane, 1856, pp. 165–6; Ross, 1835, pp. 549–71; Sabine, 1872, pp. 353–433). Contributions to the study of terrestrial magnetism in arctic Canada were also made by the International Polar Year expeditions of 1882–3 at Fort Rae (Dawson and others, 1886), Kingua Fiord (Giese and others, 1886), and Fort Conger (Greely, 1886), and of 1932–3 at Fort Rae (Stagg, 1934) and Chesterfield Inlet (Davies and Currie, 1939), which studied the daily and annual variations in the earth's magnetic field and the correlation between magnetic storms and aurorae. Important studies of the

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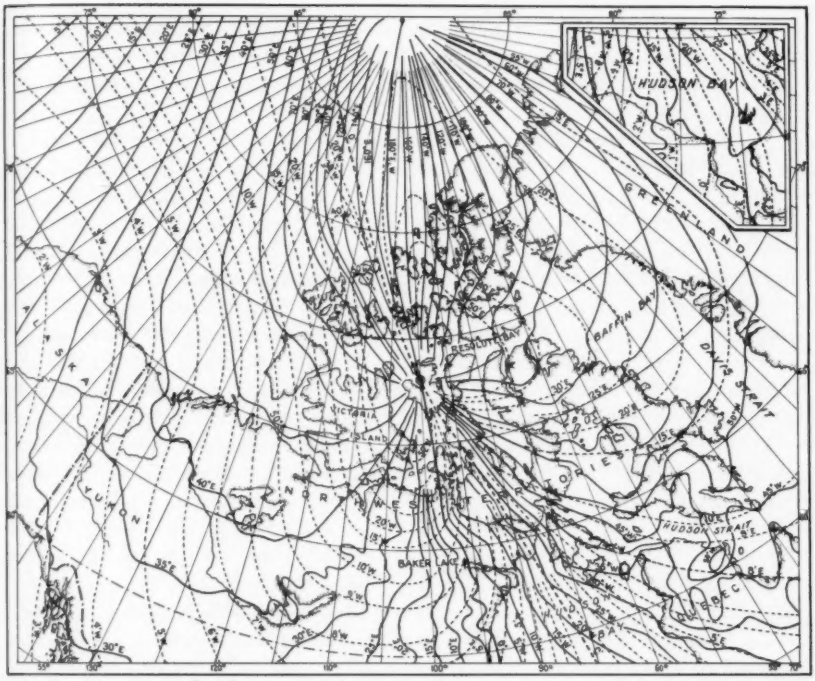

Fig. 1. Lines of equal magnetic declination and annual change in northern Canada.

earth's magnetic field in the vicinity of the north magnetic pole were made by Amundsen in 1903–6 (Steen *et al.*, 1933).

Prior to 1943 regular observations by the Dominion Observatory had extended a network of magnetic stations northwards to include the Yukon and Mackenzie river areas, and such parts of the coasts of Hudson Bay, Hudson Strait, and Baffin, Devon, and Ellesmere islands as could be reached by arctic supply or patrol vessels. Positions at which reliable magnetic observations had been made were very thinly spread over the Arctic, and consequently, magnetic maps did not possess the accuracy required for navigation with any certainty, although they illustrated in a general way the distribution of isogonic lines.

Since 1943 magnetic stations have been established, largely through the aid of the Royal Canadian Air Force, on all main islands of the Arctic Archipelago and the contiguous mainland. The stations north of latitude 60 degrees now number more than 500, and completely surround the north magnetic pole area. Information from these well distributed magnetic stations has made it possible to determine the mean position of the magnetic pole with considerable accuracy, and to construct isomagnetic maps showing lines of equal declination, inclination, and horizontal, vertical, and total force for the entire northern area of Canada (Madill, 1948, 1949). From repeated observations

made at selected magnetic stations, the annual change in the various elements is known with reasonable accuracy. The accompanying declination map, Fig. 1, illustrates present-day knowledge of the earth's magnetic field in the Canadian Arctic.

The value of magnetic results depends not only on the number of stations, and the calibre and training of the observers, but also on the accuracy of equipment. Prior to 1947 no magnetic instruments were available that would give reliable results for both the direction and magnitude in areas of weak horizontal force near the north magnetic pole. However, a new type of magnetometer, designed and constructed by Dominion Observatory personnel, was used for ground survey work in 1947 when the magnetic pole area was surveyed, and proved to be so effective that it has been adopted for magnetic surveys in other parts of Canada as well as in the Arctic. It embodies the saturable core principle, like that used in airborne magnetometers, and operates more rapidly and sensitively than older types of magnetic survey instruments.

The Dominion Observatory has established magnetic observatories at Baker Lake and at Resolute Bay on Cornwallis Island. At both observatories regular measurements of the direction and magnitude of the magnetic field are made and their changes recorded continuously by photographic and electrical variometers. These records have shown that the mean daily range of the magnetic declination at Resolute Bay, which is 120 miles from the magnetic pole, is 7 degrees. The daily variation is much greater in summer than in winter. The maximum range is in June, and amounts to 11 degrees 19 minutes, while the minimum range, in December, is 3 degrees 21 minutes. It is clear that these variations are related to the sun's declination. At Baker Lake, which is 650 miles from the magnetic pole, the daily variation is much smaller, ranging from 4 degrees in June to 40 minutes in December.

The magnetic records from these observatories, apart from their importance in theoretical research, are of immediate practical value. They furnish data which are necessary for interpreting the short- and long-term movements of the north magnetic pole, and are therefore essential for the construction of magnetic declination maps, since all magnetic meridians radiate from the magnetic pole. Moreover, they provide data which are used in evaluating world-wide disturbances in the ionosphere, and they supply essential information required in navigation and in the control of airborne magnetic surveys, which are now being carried out.

Although a satisfactory network of magnetic stations has been established, the magnetic survey of arctic North America has not been completed. A much greater density of stations will be required in the future, not only for general mapping, and further geological studies, but also for use in conjunction with airborne surveys searching for economic minerals. The success of airborne magnetometers in delineating mineralized areas depends directly on eliminating the effects of magnetic disturbances originating on the sun, which cause induced disturbances within the earth's crust. The records from the fixed magnetic observatories are therefore of paramount importance to the geophysical exploration of the Canadian Arctic.

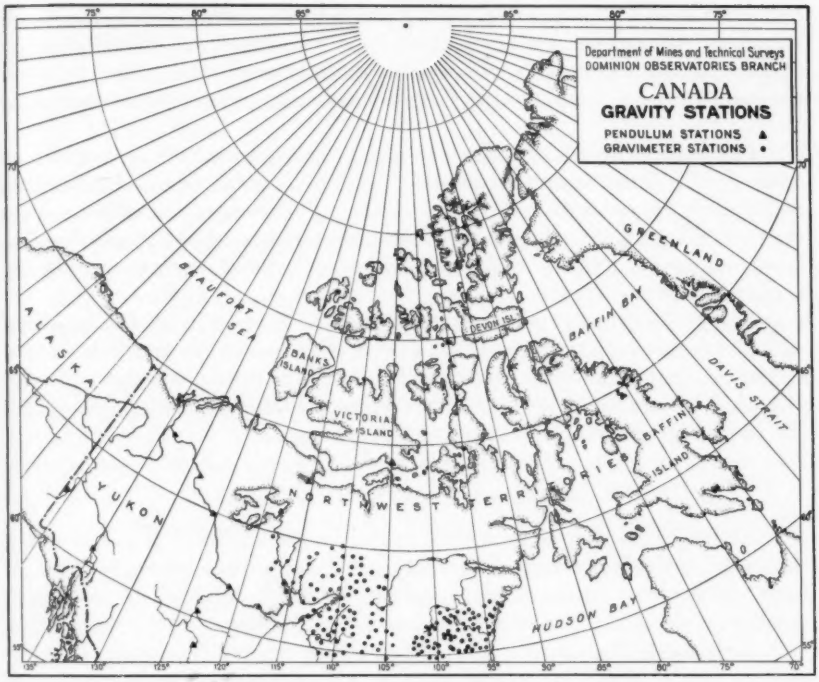

Fig. 2. Gravity stations in northern Canada.

Gravity. By M. J. S. Innes

The earliest pendulum observations in the Canadian Arctic were made by Parry on Melville Island in 1819–20 and at Port Bowen, Baffin Island, in 1824–5 (Parry, 1826), and by G. R. Putnam (1897) of the U.S. Coast and Geodetic Survey, who established two pendulum stations in 1896 in Hudson Strait and Cumberland Sound. The systematic study of gravity in northern Canada was initiated by A. H. Miller (1922) of the Dominion Observatory, who established pendulum stations in 1921 and 1922 at outposts along the Slave and Mackenzie rivers. Another advance was made in 1945 when a Canso aircraft of the Royal Canadian Air Force was employed for transportation, and observations were made at Fort Rae, Cameron Bay, and Cambridge Bay (Innes, 1948). In 1948 two more pendulum stations were established at Frobisher and Resolute Bay by scientists from the University of Toronto, who accompanied one of the icebreakers on a supply mission to the far northern weather stations (Beer, 1950).

It is now possible to measure gravity much more rapidly with modern gravimeters than with the pendulum. Nevertheless, these isolated pendulum determinations are of great value in controlling and calibrating gravimeters.

In fact, it was for this purpose, and for ensuring uniformity within the North American network of gravity stations, that the Dominion Observatory, in cooperation with United States scientists, recently established a line of precise pendulum stations from Mexico City to Fairbanks, which was completed in 1953.

Gravimeters have been used in northern Canada since 1947, to make about 2,000 gravity determinations at intervals of 10 to 20 miles, of which more than 200 lie north of the tree-line. The Dominion Observatory has made plans to continue this program, and to obtain similar gravity coverage throughout the whole of arctic Canada. The distribution of gravity observations in the Arctic is indicated on Fig. 2.

In 1950 a series of gravimeter measurements was made on the Barnes Icecap of Baffin Island in order to determine the ice thickness on the southeastern lobe of the ice cap (Littlewood, 1952, pp. 118–24). This study, which was carried out on the Arctic Institute's 1950 expedition, revealed interesting possibilities for the gravity method in the study of glaciology.

Seismology. By J. H. Hodgson

Although the first seismograph station in the Canadian Arctic was not installed until 1950, seismological studies of the area have been going on for some fifty years. Because the Canadian Arctic is bounded by European stations on the one side, and United States and Russian stations on the other, any moderate or large earthquakes in the area have been located through the routine operations of international seismology.[1] Actually the chief importance of the new Canadian station, which is at Resolute Bay, is in providing more accurate triangulation with any two stations farther south to locate epicentres in the northern hemisphere.

The new seismograph station was installed with this feature as a primary consideration. The original equipment consisted of a short-period Sprengnether vertical and two long-period Sprengnether horizontal seismographs, which provide an ideal arrangement for the recording of distant earthquakes. After a year's successful operation this equipment was increased and more extensive plans were made. Recently a long-period vertical, loaned by the Lamont Geological Laboratory of Columbia University, has been added to assist in the study of microseisms, and a three-component set of Willmore-Watt instruments may possibly be installed. These instruments will provide improved registration of local earthquakes as well as give additional data on the preliminary phases of distant shocks.

The original instruments were installed on a rock outcrop about 1,000 feet away from the meteorological station, and were connected by cables to the recording unit situated in the camp area (Bremner, 1952). The galvanometers and recorders were mounted on heavy timber cribbing, frozen into the permafrost, and were sheltered by a double-walled insulated building. This system of mounting proved so successful that experiments using permafrost as a base

[1]For a list of the principle arctic epicentres *see* Gutenberg and Richter (1949, p. 209).

for seismometers are now being carried out. A pier has been constructed on pipes driven into the permafrost, the pier being insulated carefully from the frozen ground. The new long-period vertical is at present operating with reasonable satisfaction on this base, and the proposed short-period instrument will be similarly installed.

The records are changed daily, and the readings are transmitted by radio to Ottawa, where they are relayed to the United States Coast and Geodetic Survey in Washington for use in epicentral location. Data are usually available within 24 hours, and the station has proved of considerable value in the international program of locating and studying earthquakes.

A few small local earthquakes have been recorded, but with only a single station in the area it has been impossible to locate their epicentres. Preliminary studies of microseisms have suggested a correlation of microseismic storms with storm centres over the North Atlantic Ocean, but no final conclusion has yet been reached. Finally, the recording of the surface wave L_g, at Resolute Bay, has led the Columbia group under M. Ewing (Oliver *et al.*, 1955) to conclude that the Arctic Archipelago is a part of the North American continental mass.

Arctic problems of the future. By C. S. Beals

The geophysical observations outlined above represent a beginning, in the Arctic, of the kind of systematic geophysical studies which have been carried out in more detail in southern Canada. For the most part, those branches of geophysics which are concerned with the solid earth do not make distinctions of climate or latitude. The Arctic is thus simply one more field to explore, with the proviso that transportation and living conditions are more difficult and expensive than in more southerly regions. This fact holds not only for the type of investigations already mentioned, but for commercial geophysics also. The various gold and base metal discoveries already made in areas like Yellowknife and Rankin Inlet make it practically certain that other discoveries will eventually be made farther north, and undoubtedly gravity and magnetic methods of geophysical prospecting will be used extensively. It is also known that some of the geology in the arctic islands is favourable for oil, and it will only be a matter of time before the area is fully explored with seismological methods.

Apart from the need to push geophysical exploration northward, there are a few geophysical problems specifically related to the Arctic which result from the rotation of the earth or from accidents of geography. One such problem is the location of the north magnetic pole and the fact that it appears to be moving slowly in a northerly direction. The methods used to locate the pole and to study its motion have been described by Madill (1948). Its present location is in northwestern Prince of Wales Island, and there is evidence that it has moved about 200 miles from a position in Boothia Peninsula, in slightly over a hundred years.

An interesting unsolved problem is the explanation of the position of the north magnetic pole and its counterpart in the southern hemisphere, relative to

the north and south poles of rotation. Modern theories of geomagnetism relate the major portion of the earth's field to its rotation, and it would seem reasonable to expect that the magnetic poles and the poles of rotation would coincide. It is well known, however, that the north magnetic pole is not at the north rotational pole and that a similar situation exists in the southern hemisphere. The fact that this is so constitutes a major problem in world magnetism, and one which concerns the earth as a whole and not merely the arctic regions. Nevertheless, it is a problem which is sharply pointed up by arctic observations, and one which arctic observers of geomagnetism must continue to study until a definite solution is found.

Another problem brought sharply to the fore by arctic observations is the motion of the north magnetic pole. In this connection, it should be pointed out that while most modern arctic observers are convinced that the pole is moving, the values of its position in 1831, given by Ross, and in 1904, by Amundsen, were based on much less adequate information than that of the present day. Modern scientists are grateful to Ross and Amundsen for providing good and reliable observations of great importance, but at the time their work was done, they lacked the modern means of transportation which have made it possible to surround the pole with observations, and so to fix its position with much greater exactness. It would appear, therefore, that a detailed and accurate study of the motion of the north magnetic pole is an arctic problem of the future which will certainly occupy an important place in geomagnetic studies during the next few decades. The cause of the pole's motion is beyond question bound up with the larger problem of the secular changes of the magnetic elements throughout the world, and its solution, if one is possible, will probably be on a world-wide basis. Nevertheless, no study of this matter could be complete without taking into account the arctic data on the motion of the north magnetic pole and on similar phenomena which may be observed in the antarctic regions.

There is still another intriguing problem related to the north magnetic pole which is of major interest to students of geomagnetism. If the earth, as a whole, is treated as a great magnet, the position of the magnetic axis may be derived by mathematical methods, utilizing magnetic observations over the whole surface of the globe. Such a calculation has been made, and the results show that the magnetic axis (which does not pass through the centre of the earth) cuts the earth's surface at a point in northwestern Greenland, some hundreds of miles from the observed position of the north magnetic pole as indicated by the convergence of magnetic meridians in the arctic regions. The fact that these two points do not coincide constitutes a most interesting problem. It is possible that the explanation may be found in the character of the earth's crust or of the earth's deeper layers under the arctic regions. If this is so, it seems likely that additional magnetic, seismic, and gravity observations in the arctic regions may eventually shed light on the problem. And though the magnitude of the program required to establish such a conclusion is beyond the scope of present-day transportation, these difficulties will no doubt be overcome as the Arctic becomes more developed.

Although the major part of the earth's magnetic field has its origin in the planet's deep interior, an important component has its origin in the electric currents of the high upper atmosphere. This atmospheric contribution to the geomagnetic field is strongly influenced by ultraviolet radiation and streams of charged particles from the sun. It is these influences which are largely, if not entirely, the cause of the short-term daily variations in the earth's magnetism, as well as of the violent and irregular variations known as magnetic storms. In any consideration of the position and the motion of the north magnetic pole these atmospheric phenomena must be taken into account, and it must be acknowledged that present information concerning them is far from complete. Another ten years of observation by the arctic observatories, completely covering at least one cycle of sunspot variation, will probably be required before the character of the short-term geomagnetic variations in the Arctic is completely understood.

The various magnetic problems mentioned above all require for their solution more accurate mapping of the earth's magnetic field in the Arctic than is now available. Even in southern Canada, where there is an extensive road and railway transportation network, the vastness of the country makes it difficult to establish as many ground magnetic stations as are really needed. The use of aircraft to transport ground observers, particularly in Canadian Shield areas, where water landings can be made readily, has considerably improved the situation, but even so, the number of ground stations is too few, and the areas of interpolation are too great to make possible the detailed accuracy in mapping which is desired. Airborne methods of magnetic observing are the obvious solution to this problem. Intensive development in this field has been going on both in Canada and the United States during the past few years, and some results of the United States effort, which included extensive mapping of the Arctic Ocean and adjacent areas, have been published (Hurwitz, 1953; Schonstedt and Irons, 1953). The Dominion Observatory has recently completed an airborne instrument for the simultaneous recording of all magnetic elements, and its first tests included approximately 5,000 miles of flying in the Canadian Arctic. The results of these flights have indicated that the major problems of airborne observational technique have been solved and that, as a consequence, significant progress in our knowledge of the earth's magnetic field in the Arctic is an immediate prospect.

The fact that the earth is not a true sphere, but a spheroid with an appreciable flattening at the poles, is of great interest to students of gravity. The actual shape is close to that of an ellipsoid of revolution with certain deviations in the vicinity of latitude 45° N. and S. One of the means of making precise determinations of the shape of the earth is by measurements of gravity. Ordinary geodetic measurements, for example of the number of miles in a degree of latitude at different distances from the pole, indicate that the flattening places the pole some 13 miles nearer the centre of the earth than is the equator. For very precise indications of the form of the geoid (the mathematical figure most nearly approaching mean sea level), gravity measures are necessary. Such observations make it possible to deduce, with greater

accuracy than by any other method, the various undulations of the geoid from the spheroid of reference. Undulations of this kind are produced by variations in the density of topographical features on the earth's surface and similar variations of density deep within the earth's crust, sometimes to a depth of several tens of kilometres. Deviations from the mean density of the crust are especially marked in mountainous regions and over ocean deeps, but they also occur elsewhere, and are important for understanding the equilibrium of the earth's crust, and for determining whether it is rising or sinking.

In order that studies of the earth's form should be complete, a very large amount of additional gravity data is required from the Arctic. Such observations are needed not only over the land areas but also, if possible, over the ocean, especially in the vicinity of the rotational pole. Unfortunately there seems to be little prospect of making gravity observations from the air, or of using present-day instruments with great success on ocean ice. There are certain new types of gravity meters being developed, however, which may eventually make it possible to take accurate gravity measurements on the ice of the Arctic Ocean. If, and when, this development takes place, the Arctic Ocean may actually be better mapped because of its covering of ice, than more southerly and apparently more accessible ocean regions.

Gravity observations are required not only for studying the form of the earth, but also for ascertaining the degree of isostatic equilibrium which prevails throughout the Arctic. Such studies have already been started in the region west of Hudson Bay and in the arctic islands, where there is evidence, in the form of raised beaches and altered shore lines, of considerable uplift since the last glacial age. Those gravity observations which have been made indicate that isostatic equilibrium has already been reached, and that further uplift is unlikely; but these observations are by no means complete, and it is hoped that they may be extended both in latitude and longitude during the next few years. It should be remembered, however, that while isostatic equilibrium in general indicates whether a given area of the earth's surface is rising or falling, it is not an infallible guide. Instances are known of drastic changes of level without obvious geophysical explanation. It is therefore essential that other types of measurement, such as tidal records and accurate levelling over land be made as well, if a sound knowledge of the earth's crust in the Arctic is to be gained.

In the field of seismology, not many problems have yet emerged that relate specifically to the Arctic. There is, however, a definite earthquake belt in the Arctic Ocean extending from the vicinity of Iceland to the mouth of the Lena river in Russia, but the shocks recorded there have not been intense. Earthquakes have also been recorded on the land area to the south of the Mackenzie River delta and in Baffin Bay (Gutenberg and Richter, 1949, pp. 363–78). The fact that these shocks have not been of great intensity, and that they have occurred in areas far from any major settlement has caused them to be of minor interest to seismologists who have still not solved all their problems relating to more seismically active areas farther south. Nevertheless, it may be expected that those arctic areas which have shown signs of activity will eventually be studied in more detail. It is possible that earthquake studies

carried out in these normally quiet areas may give more information about typical earth structure than those which occur in regions where the earth's crust is being subjected to major stresses of the kind which produce large earthquakes.

Another interesting problem of arctic seismology is the manner in which the surface waves of earthquakes are transmitted across the Arctic Ocean, which is shallower than the major oceans. Among the ways in which earthquake waves can be classified, we may here distinguish two main types: (a) those waves that are transmitted directly through the interior of the earth, and (b) those waves which, through their nature, are constrained to follow surface paths. Waves of type (a) have constituted, so far, the main object of seismological research. Their velocities are not dependent on their wave lengths and, in general, they move at higher velocities than type (b). Waves of type (b) are transmitted along the surface of the earth and their velocities are related to their wave lengths, the higher velocities usually being associated with longer wave lengths and *vice versa*. The relationship between velocity and wave length, however, is very different for continental and ocean paths, so that although the transmission of surface waves along continental paths and the floor of the Pacific Ocean has been studied in detail (Coulomb, 1952), a knowledge of their transmission across the shallower Arctic Ocean should prove interesting and valuable. At present, such a study is rendered difficult by the lack of seismograph stations both on the North American and Eurasian shores, although improvements in transportation, and the development of portable, yet accurate, seismological instruments should eventually make such studies practicable. When these improvements come about, a new approach will be possible to the study of surface waves as well as other problems of arctic seismology.

Both astronomy and geophysics have been involved in certain recent developments in the Arctic connected with meteors, meteorites, and meteorite craters. While some of the solid bodies which enter the earth's atmosphere from outside space reach the ground relatively intact, the vast majority are disintegrated at considerable heights by the intense heat generated by friction with the air. One of the products of such disintegration is meteoric dust, which consists mainly of small spherical particles, probably formed of molten material swept from the hot surfaces of meteors as they move through the atmosphere.[1] It is clearly important to distinguish between meteoric particles and those of terrestrial origin. The large ice- and snow-covered areas of the Arctic are very well suited to this purpose, and it is hoped that the collection and analysis of meteoric dust from snow surfaces may take an important place in the work of the increasingly numerous arctic stations.

Of the meteoric bodies large enough to reach the ground, only the larger ones are normally found, since most of the smaller meteorites are either buried in the soil or have become indistinguishable from their surroundings through weathering. An exception is found in those small meteorites which fall on ice

[1]For a brief description of methods of collecting and analysing meteoric dust *see* Thomson (1953).

surfaces, and are clearly visible because of their darker colouring. A number of interesting meteorites have already been detected in this way, and it seems likely that when more people are living or travelling in the Arctic, an increasing number may come to light. Certainly any piece of rock with no obvious local origin, found on an ice surface, should be examined carefully for a possible meteoric origin.

Another arctic connection with meteoric phenomena is the great Ungava crater,[1] northwest of Fort Chimo, which is generally believed to be of meteoric origin (Meen, 1950; Meen and Stewart, 1952). If it is a meteoric crater, it is the largest so far observed on earth, being between two and three miles in diameter. It is now known to be preglacial in age although recent in geological time, and has been little altered by erosion. These factors have given it unusual scientific importance, and it is being studied from several points of view, one of which is a mathematical investigation of the physical mechanism responsible for explosion crater formation. One reason for the great interest in large craters of this kind is their possible relationship with craters on the surface of the moon, which are also believed to have a meteoric origin. Because of its size, the Ungava crater affords by far the best opportunity for comparing terrestrial and lunar craters. It seems likely that at one time the number of craters on the earth and moon was comparable, but that erosion and deposition obliterated almost all traces of the really ancient terrestrial craters, leaving only a few of relatively recent age. Nevertheless, it seems probable that if sufficiently detailed studies were made in remote parts of the Canadian Shield, which has remained free of major geological changes for a very long time, some indication of ancient craters might be found. One circular feature, which may possibly be such a crater, has been discovered in Algonquin Park. But it is also true that on several arctic islands, for example, Ellef Ringnes, Axel Heiberg, and Melville, a number of circular features which were thought at first to have been caused by meteors, later appeared to be due to other causes. In spite of this it is possible that the Arctic may contain some of the most important clues necessary for solving the intriguing puzzle of lunar craters and their relationship to terrestrial phenomena.

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THE IONOSPHERE OVER NORTHERN CANADA

Frank T. Davies*

COMMUNICATION problems in northern Canada, as elsewhere, are primarily a matter of cost. In densely populated areas the great volume of communications justifies expenditures for telephone, telegraph, and multi-channel radio-relay networks, supplemented by the broadcast facilities of AM and FM radio and of television. In the north the present population is too small and widely scattered and the potential volume of communications too little to justify the expense of elaborate facilities. The most economical method of providing fast communication for the area is by short-wave radio via sky-wave transmission, as the installation and the electrical power required are relatively small. More specifically, short-wave radio means propagation via the ionosphere, an electrified reflecting layer between 60 and 200 miles above the earth's surface, on radio frequencies between 3 and 30 megacycles. Today, most of the small northern settlements of Canada possess short-wave radio equipment.

Short-wave radio systems, although reliable most of the time, suffer from occasional failures owing to disturbances in the ionosphere. Unfortunately, the ionosphere over a great part of northern and central Canada is often more disturbed than it is over most other regions of the earth because the earth's magnetic field approaches the vertical, allowing charged particles from the sun to penetrate more deeply into the earth's atmosphere over these regions. The auroral, or northern light zone, coincides with the southerly two-thirds of this region. Although auroral and magnetic phenomena are often associated with ionospheric radio disturbances the aurora is rarer farther north, but the ionosphere is still very much disturbed. Short-wave radio therefore suffers from interruptions throughout the auroral zone and into the polar area.

The pressing economic need to make the best possible use of short-wave radio in Canada has led to intensive observation and study of the ionosphere, and has stimulated research into other phases of the physics of the upper atmosphere. To study ionospheric changes, the Telecommunications Division of the Department of Transport, in cooperation with the Radio Physics Laboratory of the Defence Research Board, has established eight ionospheric recording observatories.[1] Four of these, at St. John's, Newfoundland, Ottawa,

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[1]Another ionospheric station was set up by the Carnegie Corporation at Clyde in 1943 and was taken over by the Department of Transport in 1945; it has now been discontinued.

Winnipeg, and Prince Rupert, skirted the southern part of the auroral zone from east to west. Stations at Churchill and Fort Chimo were near the line of maximum auroral occurrence, and those at Baker Lake and Resolute Bay extended the line of observations from Winnipeg, in the south, to a point north of the magnetic pole. For several years measurements of the height and electrical density of the three main levels of the ionosphere have been continuously recorded by means of variable frequency radar at all of these stations. In 1954 the stations at St. John's, Fort Chimo, and Prince Rupert were discontinued.

From observations already obtained it is possible to predict the average height and electrical density of the ionosphere for a given time of day and season of the year, and therefore to select the best radio frequencies for specific short-wave paths over most of Canada. Studies of ionospheric disturbance have also shown that interruptions to short-wave radio are more frequent in the spring and fall than in the winter and summer. They are also more frequent in years of high sunspot activity, such as 1947–9, than they are in years of minimum activity, such as 1954–5. Some success has now been achieved in forecasting ionospheric disturbances as much as a month in advance.

The radio-noise level of northern Canada is low compared with that of southern Canada, which in turn is lower than that of tropical regions. Weaker radio signals can be detected and used in the north than elsewhere, so that relatively little transmitter power is required. One reason for the absence of noise is that intense radio energy from the numerous tropical thunderstorms diminishes rapidly at a distance of 4,000 miles. Noise from local thunderstorms, and from machinery and radio equipment is also low in the north, even during the summer, when the general noise level is higher.

This relative lack of noise and the improved methods for selecting radio frequencies, have made short-wave communications in northern Canada reliable about ninety per cent of the time. Unfortunately, the failures may occur in periods of one to three days at a time. This is not important for ordinary traffic since delays of this order are infrequent, but for urgent traffic, such as reports on sickness or weather, it is a serious handicap. Any short-wave circuit which is less dependable than ninety per cent should be checked for the condition of the equipment and the suitability of the radio frequency. If the frequency is too high for a given path the receiving station will be within the "skip-distance" of the sending station. If the frequency is much below the correct value its energy may be absorbed in the lower atmosphere instead of being reflected. Advice on the best radio frequencies and times of day for specific paths can be obtained from the Radio Physics Laboratory of the Defence Research Board at Ottawa.

Ionospheric research has also opened up a wide range of theoretical and experimental problems, particularly in high magnetic latitudes. The science of the physics of the upper atmosphere, of which the ionosphere is a part, is being given increasing attention in Canada and is bringing closer cooperation between theoretical and experimental physicists and radio engineers. Intensive research on the spectra, luminosity, height, and electron density of the aurora

is being made at the Physics Department of the University of Saskatchewan. The correlation between auroral, ionospheric, and magnetic disturbances is also being investigated at this university in cooperation with the Radio Physics Laboratory in Ottawa. It is hoped that a spectrograph of very high dispersion designed by the Radio Physics Laboratory for use at Churchill, will give much more detailed auroral spectra than have previously been obtained, and will enable more exact determinations to be made of the constitution, energy changes, and temperatures at different levels in the upper atmosphere. Parallel with these auroral measurements, a laboratory study is being made of artificial aurora produced in discharge tubes.

A joint project of the Dominion Observatory and the Radio Engineering Division of the National Research Council is yielding interesting information on meteor showers and the ionization produced by meteors in the lower atmosphere. Investigations of aurora and other ionization processes of the upper atmosphere are being extended northward and should give further information about one of the most complex regions of the ionosphere. It is hoped that the formation of the advisory committee on radio science by the National Research Council will stimulate further interest in the ionosphere.

Three main problems of the ionosphere over northern Canada, as elsewhere, remain unsolved.[1] Each is complex, and requires subsidiary investigations employing radar, spectroscopy, and magnetic and radio-signal strength recording. First is the problem of forecasting storm conditions in the ionosphere in order to improve radio communications. While the complete solution of this problem is not urgent in low latitudes, it is very important for Canada. Second, the nature of the extreme ultra-violet radiation of the sun is not sufficiently understood, and should be thoroughly investigated in the ionosphere and other parts of the upper atmosphere. Improved techniques of rocket measurements made by United States engineers should be very helpful in this regard, and may even bring our knowledge of extreme ultra-violet radiations in the upper atmosphere near completion. Third is the puzzling problem of winds and tidal effects in the upper atmosphere. In several countries radar techniques for measuring winds in the ionosphere have yielded challenging results. Continued investigations will undoubtedly throw increasing light on this interesting question.

[1]For a discussion of subsidiary problems *see* Mitra, S.K. 1952. 'The upper atmosphere'. Calcutta: The Asiatic Society, 713 pp.

GEODETIC INVESTIGATIONS IN THE CANADIAN ARCTIC

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THE first step in the scientific investigation of an undeveloped district is accurate mapping. Where geodetic surveys, whether by astronomy, triangulation, or by shoran trilateration, are used to establish the necessary control for mapping, the data obtained are also of value in computing deflections of the vertical, in determining the undulations of the geoid and the thickness of the earth's crust, and finally, in deriving the dimensions of the spheroid of revolution which conforms most closely to the geoid.

Over the last one hundred years, geodesists in different parts of the world have derived the mathematical dimensions of five spheroids which are in reasonably close agreement. The ultimate aim of the research is to derive a geoid and a spheroid from data which are world-wide in coverage, and therefore free from the effects of local anomalies. In the Canadian Arctic and Subarctic methods of survey based on geodetic astronomy and shoran trilateration have already been used. In the foreseeable future, geodetic triangulation and precise levelling will also be used and should advance geophysical research in these regions.

The Geodetic Survey started its arctic work in 1935, when C. H. Ney determined the astronomical positions at some of the points of call of the Hudson's Bay Company's R.M.S. *Nascopie*. In 1942 the northern operations of the Geodetic Survey were expanded, and between that year and 1950, 300 astronomical stations were established for control for mapping from air photographs north of the tree-line. About 200 of these were on the mainland, the remainder on the more southerly arctic islands.

The determinations were made by Ball's method, using a precision theodolite set at a vertical angle of 45 degrees or 60 degrees. A minimum of four stars was observed in each quadrant, and the time recorded by stop watch or electric chronograph. In favourable weather a party could complete four to eight stations a month. Occasionally prolonged periods of overcast skies prevented astronomical work. During such periods hourly magnetic observations were taken in the daytime, and botanical and zoological collections were made by some of the parties.

During the past few years the shoran electronic method of position fixation has superseded the astronomic method in most parts of northern Canada. This new system of survey permits the extension of ground control for mapping and charting into remote areas in a much shorter time than would be required by

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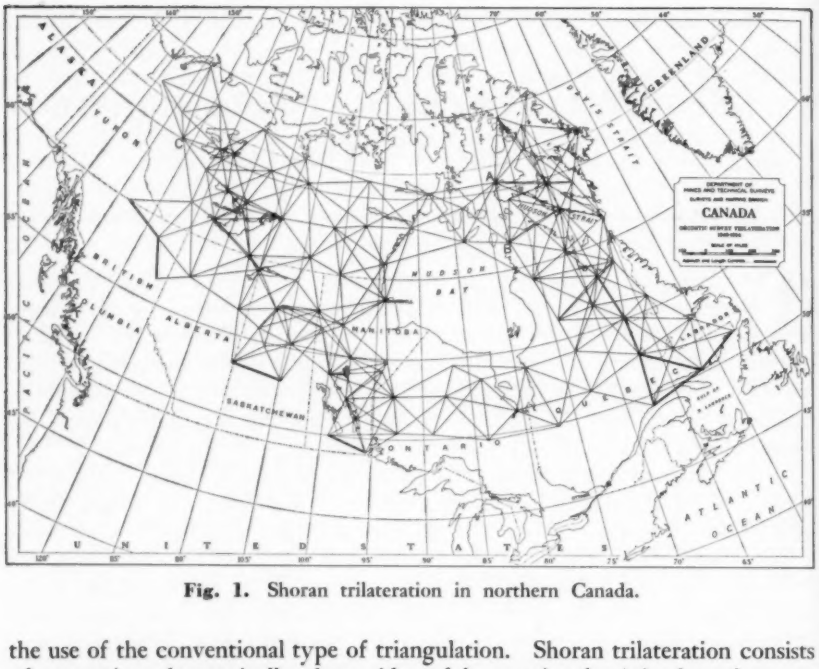

Fig. 1. Shoran trilateration in northern Canada.

the use of the conventional type of triangulation. Shoran trilateration consists of measuring electronically three sides of large triangles joined to form an over-lapping series of geometrical figures. The triangles are extended initially from a known base line joining two previously determined geodetic triangulation stations. By the shoran method distances between points up to 400 miles apart may be determined with an accuracy of 20 to 50 feet.

Through the cooperation of the Royal Canadian Air Force, airborne electronic equipment is used in conjunction with ground sets mounted temporarily at the terminal stations of the line being measured. The aircraft flies back and forth across the line near its central point at uniform speed and height, emitting short radio pulses which are sent to the terminal ground stations and then returned on a different frequency after a very short fixed delay. The elapsed time between dispatch and reception is recorded by mileage dials, which together with other dials are photographed at intervals of three seconds.

Immediately after the return of an aircraft from a line-crossing mission, Geodetic Survey personnel at the operational base camp receive the photographic records of instrument readings and make the necessary mathematical reductions. Corrections to each length obtained are made for delay of signals at the ground stations, height of aircraft and terminal stations above sea level, slope, humidity, temperature, and barometric pressure. Sixteen independent length determinations are made of all lines on two separate days in groups of eight each to ensure a change of atmospheric conditions and to check equipment. Further mathematical checks are made where possible. When field

analyses are satisfactory, the ground electronic equipment, consisting of transponders, radio communication sets, power supply units, and radar masts, are dismantled and moved forward to new stations in the network. The final least squares adjustment of the network as a whole, and the computation of geographical positions, azimuths, and lengths are made by the Geodetic Survey in Ottawa.

Since 1949 the Canadian shoran net has been extended from the vicinity of the 49th parallel in Manitoba, north and northwestward as far as the arctic coast in the Mackenzie River area. Beginning some 200 miles to the south of the northern point reached in 1951, a branch was continued eastward 1,000 miles to the western limits of Hudson Strait by the end of 1952. During 1953 the network was extended northward across Hudson Strait to the central part of Baffin Island, and a junction was made near the western end of Hudson Strait with the existing shoran net. This junction completed a 5,600-mile closed loop of survey control. The southern part comprised a 2,000-mile arc of conventional triangulation; the remainder consisted of shoran trilateration. The closure error in geographical position was equivalent to 400 feet. If it is assumed that the entire error was accumulated in the 3,600-mile shoran component of the loop, the ratio of closing error to axial length is only 1/47,000, equivalent to 1⅓ inches in one mile. In 1954 the shoran work was continued in Labrador, more stations being established within the basic framework.

Since its inception in 1949, shoran trilateration had been extended by the end of the 1954 season over 1,900,000 square miles of the Canadian north, a large part being north of the 60th parallel. In all, 86 stations involving 325 measured lines ranging from 16 to 366.8 miles in length are comprised in the network.

Problems and future work

One of the major undertakings for Canadian geodesists will be the extension of primary triangulation arcs from the more southerly areas into the Arctic, so that connections may be made with the northerly sections of the shoran network. This will greatly strengthen mathematically the existing shoran framework in addition to providing a dense pattern of control points in specified areas between the shoran stations.

Geodesists foresee interconnection of the geodetic triangulation networks of Europe, Asia, and Africa with those of North America. This may conceivably be achieved by shoran trilateration connections across Bering Strait, or between the Canadian Arctic shoran net and the triangulation systems of Greenland, Iceland, and the British Isles. A project of this nature would make possible the establishment of a "world geodetic datum" to which all triangulation and trilateration surveys on land masses within electronic measurement distance of the interconnected continents could be referred.

One great advantage of a "world geodetic datum" would be the coordination of data from isostatic studies in various countries. Deflections of the vertical determined in the Canadian Arctic by geodetic methods could be

accurately related to values observed in England or Africa. In this way, the studies of the geoidal contours and the determination of the best-fitting spheroid of revolution would be greatly advanced.

Gravity observations would be an important part of a planned world program for the study of geophysical problems. If gravity observations were available for all parts of the world on both land and water, an extensive mathematical reduction by Stokes's Theorem would permit accurate calculation of the undulations of the geoid and the extent of the flattening of the earth towards the poles. But from gravity observations alone it is not possible to compute the lengths of the major and minor axes of the earth. At the present stage of development of the science, a combination of astronomy and geodesy constitutes the most effective and practical approach to the determinations both of deflections of the vertical and of the dimensions of the spheroid of revolution which most closely conforms to the size and shape of the earth. The usefulness of the two methods of approach to the study of variations in densities of the earth's crust is suggested by recent findings in the Great Bear Lake region, where the geodetic shoran network has indicated large anomalies in the general pattern of deviations of the vertical. An intensive gravity survey in the same area might provide technical data of both scientific and economic value.

Geodetic investigations of changes in mean sea level should be extended to the Arctic. With the ameliorating climatic conditions of recent years in the north the weight of the glacial remnants has been reduced and increased amounts of water from melting ice have found their way into the sea. The resulting diminution of pressure in several areas may be expected to cause isostatic readjustments of the earth's crust, either suddenly, accompanied by earthquakes, or very slowly in the form of a gradual tilting. Such a tilting has been definitely indicated over a period of years by geodetic levelling in the Great Lakes region both north and south of the international boundary. The alterations in mean sea level can best be measured by repeated levelling over selected lines at intervals of about twenty years. Changes indicated by coastal tide-gauge stations and permanent bench marks, situated at intervals along the lines, will also give a measure of the crustal tilting.

The basic problems of geodesy in the Canadian Arctic are similar to those in other parts of the country, but the amount of geodetic work already done in the north is small compared with that in the south, and increased knowledge of the north would be of great benefit in all geophysical research.

OCEANOGRAPHIC PROBLEMS OF THE ARCTIC OCEAN

C. O'D. Iselin*

The central problem in oceanography is to understand the movements of the water. This is true whether a study is primarily concerned with the physics, the chemistry, or the biology of the sea. Although the oceanographer deals with much slower movements than the meteorologist, he is beset by many of the same sorts of questions. To both, the motions observed occur within a relatively thin fluid envelope on a rotating earth. To both, the scale of the motions of interest covers a very wide range and both periodic and non-periodic motions are involved. Over most of the oceans the winds and the currents interact in many subtle ways, and it is often difficult to distinguish between cause and effect.

While it has become clear that ocean currents derive much of their energy from the winds, it is also evident that heating and cooling play a significant role. Some currents are almost pure wind currents; others are maintained largely because of regional differences in density. In most currents both causes are at work, and it is usually extremely difficult to establish their relative importance. However, much of the theoretical work in oceanography has been in connection with wind currents, as theories that can help to explain the characteristics of currents that are partly wind-driven and partly density-driven are beset by great mathematical difficulties. In the past, at any rate, theoretical studies have been most helpful in physical oceanography after the physical characteristics of the situation could be described in a reliable manner. In oceanography theory alone has seldom led to advances.

The exploratory stage of arctic oceanography is now drawing to a close. In very general terms the physical, biological, and geological characteristics of the area can be described as the result of a number of arduous and costly expeditions. To an oceanographer the Arctic Ocean is no longer an unknown sea. Ice-free waters that are just as cold are available to him elsewhere, and to be able to reach higher latitudes does not in itself hold promise of advancing his primary problems. But the arctic region[1] can make an important contribution to physical oceanography. As Worthington (1953) has shown, the

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[1]In this paper Dr. Iselin is concerned with the Arctic Ocean basin only, not with the waters of the arctic islands, Canadian coastal waters, Baffin Bay, or Hudson Bay. *Ed.*

Arctic Ocean is the only sea in which circulation occurs down to very considerable depths in the absence of any significant supply of energy from the local winds.

The circulation of the Arctic Ocean therefore presents a unique problem in physical oceanography. The winds can move the ice to some degree, as several expeditions have shown, but the frictional effect of the ice on the water must be minor compared with the regional differences of density, level for level, between the truly arctic waters and those of the Norwegian Sea. Moreover, recent knowledge of the topography of the Arctic Ocean Basin shows that the problem is even more interesting than it was previously thought to be. Only five years ago, when Sverdrup (1950) reviewed our knowledge, or rather lack of knowledge, concerning the physical oceanography of the arctic basin, he could not have realized that it was cut in half by a pronounced ridge. Worthington (1953) later suspected this, but it is only since the results of the Soviet expeditions have become known that it was certain bottom topography must profoundly influence the deep circulation (Webster, 1954).

Thus, a significant challenge faces students of oceanic circulation problems: Here is a sizable, deep basin covered with ice, one half of which is connected directly to another deep basin—the Norwegian Sea, which is largely ice-free—and the other half of which is to some extent isolated by the newly discovered Lomonosov Range. While the velocities of the currents under the ice may be weak, Worthington's (1953) calculations indicate that considerable transports are involved, even in the remote part of the basin. How can the study of the main problem that this area presents be advanced, what sorts of facilities are required, and what factors peculiar to the Arctic are favourable or unfavourable? In comparison with other large-scale aspects of the circulation problem the situation on the whole appears to be favourable, and undoubtedly many other interesting oceanographical phenomena will be encountered in the course of studies of the arctic circulation.

The primary assumption in deep sea oceanography, namely, that the flow is relatively steady so that a balance of forces exists, is probably most fully justified in the Arctic Ocean because the disturbing effects of the local winds are mostly eliminated. Thus, in the Arctic the necessity for simultaneous observations is largely removed and observed and computed currents can be compared with considerable expectation of agreement, especially since the disturbing effects of internal waves are probably largely eliminated, even though the collection of a deep network of temperature and salinity observations may have required a considerable period of time. In addition, even though the currents are relatively weak, it should be easier to obtain accurate measurements of the change of velocity with depth working from the ice, a very favourable platform for current measurements, than is ever possible from a ship. At lower latitudes an oceanographer has to study currents that he is virtually unable to measure with the desirable accuracy. Since the currents in the Arctic Ocean are probably slow, broad, and relatively steady, a rather open network of points of observation should suffice. A satisfactory analysis

could emerge even though the points of observation were separated by as much as 100 miles on the average. As oceanographers have learned during the last few years, a considerably closer network of nearly simultaneous observations is essential in seas that are exposed to the winds.

Although in the Arctic a comparatively small number of points of observation may well suffice, the oceanographer is faced with a serious, but not necessarily expensive, transportation problem. An aircraft is considerably cheaper to operate per mile than a sea-going vessel, but the difficulty at present seems to be that nobody has designed an aircraft specifically for arctic oceanography. An aeronautical engineer with this purpose in view would certainly be facing a limited market, but the fact remains that reliable and economical transportation is the chief requirement of arctic oceanography. All other aspects of a productive observational program could be solved fairly quickly on the basis of existing knowledge and experience. Most of the readily available instrumentation of oceanography has been designed to withstand the normal conditions at sea, a heaving ship and a ready supply of power, rather than to operate in the ice and to meet the requirements of an airlift. But to devise oceanographic instruments in miniature and otherwise to improve them for use in the Arctic could be quickly achieved, the bottle-neck for the time-being is the transportation. To set up camps on the ice and to depend on the slow drift of the ice to gain coverage, as has usually been done in the past, does not seem the most efficient way to attack the majority of arctic oceanographic problems. The requirement is to move two trained observers and perhaps 1,000 pounds of equipment to a network of points separated by about 100 miles and to give the men a few hours at each station to make their observations. Until such transportation is available most oceanographers will find it more profitable to study problems for which advances can still be made from ships, and most of the gains in arctic oceanography will probably continue to come as a by-product of expeditions whose objectives are not limited to the classical problems of oceanography.

During the summer season many interesting studies can of course be carried out along the shallow margins of the Arctic Ocean, even from quite small craft. From the ecological standpoint especially, such expeditions will continue to be profitable for many years to come. Another possible approach for both summer and winter work would be to design radio-telemetering instruments that could be air-dropped into open leads to secure observations from the deeper parts of the Arctic Ocean, but until the problem of precise aerial navigation is solved, landing on the ice with the oceanographic instruments will be a sounder method. A reliable geographical fix is especially critical in the case of physical measurements. Nor could a submarine at present really solve this need for accurate navigation, except in so far as it were practicable to surface in open leads. Where am I? and just where is my instrument relative to my position? become increasingly important questions as oceanography emerges from the exploratory stage. These are difficult enough questions to answer with precision from a ship, even in areas where

the latest navigational techniques are available. Thus, although mobility is important to an oceanographer, he must also be able to fix his location at frequent intervals.

While the difficulties of transportation may seem considerable today, the Arctic Ocean has at least two great attractions to an oceanographer: It is not nearly as large as, say, the Pacific Ocean, and the ice provides a nearly ideal platform from which to work.

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TIDAL DATA IN THE NORTH AMERICAN ARCTIC

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KNOWLEDGE of tidal conditions in North American arctic waters is meagre when the vast area of these waters and the great extent of the coastal shorelines are considered. Tidal observations are difficult to obtain due to the prevalence of ice, scarcity of inhabited areas, and the inaccessibility of the region. Available data are inadequate, sometimes of dubious quality, and frequently insufficiently distributed to permit a proper study of the tidal regime. In many areas the range of the tide is small and therefore long periods of observations are necessary to separate comparatively large variations due to meteorological conditions from true tidal fluctuations.

Prior to 1945 the tide had been observed at only a few places along the Arctic Ocean coast of Alaska and Canada. In the last ten years observations have been obtained at about twenty additional places. These additional observations are sufficient to establish that the range of tide along the arctic coast of Alaska, east of Cape Lisburne, is only about one-half foot. The limited durations of the observations do not provide data for long-period investigations of sea level variation. Tidal harmonic constants have been derived for Cape Columbia and Cape Sheridan, Ellesmere Island. They are based on a 29-day series in 1908 and 220 days in 1905 to 1908 respectively.

Tidal observations in the numerous channels between the islands of the Canadian Arctic ordinarily supply local information only and inferences on tidal conditions in nearby channels would in general be unreliable. The observations at Winter Harbour, Port Kennedy, Port Leopold, Beechey Island, Penny Strait, and Discovery Harbour are of sufficient length for harmonic analysis and the tidal constants necessary for predictions are available. Shorter periods of tidal observations are being obtained at an increasing number of other stations in the area, particularly the far northern weather stations.

In Hudson Bay and Hudson Strait there is a reasonable coverage of tidal observations, except for the southern and eastern parts of the bay. More stations are still required, particularly in Hudson Strait where the exceptionally large range of the tide makes a greater than normal density of tidal stations necessary. Harmonic constants are available for Churchill and Diana Bay, and sufficient data have been obtained for harmonic analysis from Port Nelson, Rankin Inlet, Chesterfield Inlet, Coral Harbour, Koksoak River, Leaf Basin, and Leaf Bay.

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For the waters of Baffin Bay and Davis Strait the consistency of the available data permits a fairly satisfactory interpretation of the tides although the coverage is inadequate. Along the western coastline of these waters, harmonic constants are available for Kingua Fiord, Cumberland Sound, from a 41-day series in 1883 and for Frobisher's Farthest, Frobisher Bay, from a 29-day series in 1951. The coast of Greenland fronting these waters is more adequately covered in the southern portion. There are harmonic constants for eight stations: Nanortalik, Julianehaab, Ivigtut, Godthaab, Godhavn, Rifkol Ø, Kronprinsens Ejland, and Ingnerit.

Along the northwest coast of Greenland from Port Foulke northward, there are five tidal stations including two facing the Arctic Ocean. Harmonic constants are available for all five: Port Foulke, Rensselaer Bugt, Thank God Harbour, Kap Bryant, and Kap Morris Jesup. On the east coast of Greenland tidal data are available for ten places, seven of which are clustered between latitudes 70° and 77°N. Harmonic constants are available for four stations: Danmarks Havn, Lille Finsch Ø, Danmark Ø, and Finnsbu.

There are indications of varying types of tides in all these waters. It would appear that Bering Sea has little effect on the tide in the Arctic Ocean; in the waters about the islands of the Canadian Arctic there is a semi-diurnal tide with a moderate inequality; different types of tide exist along the coasts of Greenland as indicated by the harmonic constants; there is a substantial diurnal tide in the Arctic Ocean north of Greenland as opposed to a less complex semi-diurnal tide in the nearby North Atlantic waters.

The establishment of additional tidal stations is necessary and series of observations must be made over longer periods before a complete study can be made of the tidal regime of the arctic waters. Additional observations, if made over a sufficient period, will show regional tidal characteristics in various places. Whenever facilities and opportunities are available, observations should be made in the offshore areas of the extensive Arctic Ocean basin. Depth soundings should usually be made at these locations.

New techniques will be necessary to obtain the improved observations in arctic regions. A series of at least three bench marks should be established and connected by levels to the datum of the observation at each station. Proper procedure for subsequent observations at the same station would provide correlated data over a longer period and would enhance the value of any limited observation.

Geophysical changes have been noted by secular variations in sea level along other coasts of North America, where systematic tidal observations have furnished data on the slow changes which have taken place in the relative elevation of the land to the sea. There is little or no basic data now available for detecting geophysical changes in the arctic region of North America.

SEA ICE STUDIES

Terence Armstrong*

ALTHOUGH there is a considerable literature (U.S.A., 1945) on sea ice, its structure and behaviour is still very imperfectly known. Until twenty-five years or so ago, study of the physical properties of ice was concentrated, for practical reasons, more upon freshwater ice. The greater part of the sea ice literature has been concerned with distribution, and description of the various sorts of sea ice and their classification. One may mention as one of the outstanding works Wright and Priestley's memoir (1922). Several notable contributions were also made to sea ice physics, particularly by Malmgren (1927).

The remarkable growth of interest in the polar regions over the last two or three decades has led to greater attention to sea ice problems. The reason is of course that study of sea ice is fundamental to the movement of shipping into the polar regions and this in turn is fundamental to development of almost all kinds. So the main application of sea ice studies is to shipping. There are other applications: to aircraft seeking to land on ice, to vehicles seeking to cross a frozen strait, to climatologists wishing to use ice conditions as an index to climatic change, and to synoptic meteorologists interested in the effect of ice on the dynamics of air masses. But none of these is likely in the foreseeable future to eclipse the need of the shipmaster, so that most research will be conducted with this end in view.

Ice studies today tend to fall into several subdivisions. First of all there is pure research, which is concerned with the fundamentals of structure and behaviour. It is the direct continuation of the earlier work: description and classification, leading to detailed study of the physics of sea ice. This work has been carried out in many countries, notably the U.S.S.R., the Scandinavian countries, the U.S.A., Canada, Britain, Germany, and latterly Japan. Published work is widely scattered and not easy to assemble. The only attempt to bring it together has been that by Zubov (1945); his book is most useful, but the author insists it is not to be thought of as a textbook since it contains many of his own views which still require confirmation. The text is entirely in Russian, but a translation of parts has been made by the U.S. Navy Department. Current work in the U.S.S.R. on sea ice physics is not known. A summary published just after the war by Laktionov (1945) indicates its extent,

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and leading specialists such as Zubov, Somov, Gakkel', Gordiyenko, and Volkov have been active in planning and carrying out the work of drifting stations on the ice of the Arctic Ocean from 1948 to the time when this account was written in 1955. So it is to be assumed that much work is being undertaken. Outside the U.S.S.R. the most active centre is the U.S. Navy Electronics Laboratory's Arctic and Submarine Branch, which embarked in 1954 on a comprehensive long-term program of research. A point worth underlining is the change from individual to team-work. In contrast to the quite recent past, ice physics can no longer be importantly advanced by the gifted amateur studying the natural history of sea ice.

Research on the fundamentals naturally affects the other branches of sea ice study. But the latter are sufficiently distinct to be considered separately. They are closely linked with practical demands of ship navigation, and may therefore be called applied research.

At its simplest, the provision of ice information for ships consists in issuing statements as to where ice was last observed. This is comparatively straightforward, and is done today by many agencies in many parts of the world where ships may meet ice. Two main problems are posed by the sending and the receiving of these messages: terminology, and methods of transmission.

Terminology has been most confused. Quite apart from linguistic differences, there have been numerous duplications and overlaps of definition in the English terms. Glossaries attempting to clarify the position have recently been produced by the U.S. Navy Hydrographic Office (U.S.A., 1952), by the Admiralty Hydrographic Department with the help of the Scott Polar Research Institute (G.B., 1953), and by the World Meteorological Organization (Switzerland, 1952). The last two are quite closely similar. But the W.M.O. glossary has been published as a draft only. As such it has already formed the basis for usage in Scandinavia and elsewhere, but it is now likely to be revised owing to the recent belated agreement of a Soviet representative to join the working group. Thus the terminological problem has not yet been solved. But there seems a good chance that agreement among English-speakers may not be too far distant; and once this is achieved, it should not be difficult to link in the other languages by means of linguistic equivalents. Work on this is proceeding.

The chief problem of transmitting ice information is in the use of codes. Codes are necessary in order to economize signal time, but it is difficult to adapt them to ice information. Solutions have been found for areas where the ice is not complex—the Baltic, for instance—but the problem as a whole is not as near solution as the terminological question may perhaps be. International agreement must be the ultimate goal; but at the moment such ice codes as the World Meteorological Organization has approved do not meet the need in the polar regions. Remedies are under consideration, however. Meanwhile, most ice messages to shipping are given in plain language. But the U.S. Navy in 1953 adopted facsimile transmission of ice charts by radio. This is by so much the best solution that its use must ultimately become general.

The next stage beyond reporting the present state of the ice is forecasting. Here one may distinguish the same division which exists in meteorology between climatology and synoptic meteorology. On the one hand there is the use of past records to assess, say, the probability of access to a given place at a given time of year; such researches may be termed ice probability studies. On the other hand, there is the use of present observations to predict the movement of the ice a short time ahead—synoptic ice studies. Both lines of approach have been investigated.

Ice probability studies have led to the publication of ice atlases, in which the likelihood of meeting ice at particular places is shown for different times of the year. The U.S. Navy Hydrographic Office produced one of the northern hemisphere (U.S.A., 1946), and Deutsches Hydrographisches Institut another, which included both polar regions (Büdel, 1950). These give, as intended, a very general picture, which is constructed from the comparatively few known facts with much interpolation. An attempt to give a picture which avoids interpolation and in which the factual basis is clearly set out has been made by the writer and is in course of publication (Armstrong, in press). Studies, which will be broadly similar to this is conception, are about to be undertaken for two more areas: Canadian arctic waters north of Hudson Bay and Strait, and the Graham Land region in the Antarctic.

Synoptic ice studies may be divided into the technique of forecasting and the organization of ice observing. In the technique of forecasting, by far the most work has been done by Soviet research. Since about 1935 more than a dozen Soviet scientists have been examining in detail the factors influencing drift, growth, and decay. A summary in English of their progress up to about 1941 (which is the most recent information available outside the U.S.S.R.) has been published (Armstrong, 1955). Since 1952 the U.S. Navy Hydrographic Office, which has been responsible for ice forecasting in North American arctic waters, has been developing its own techniques, which are largely based on what is known of the Soviet work. Meanwhile for Finnish waters Jurva (1937) studied the pattern of ice development in past years and was able to distinguish trends which could be used for forecasting. In general, the technique of ice forecasting is still in its very early stages (outside the U.S.S.R., where recent progress cannot be evaluated). Further development is likely to be closely linked to advances in sea ice physics.

The organization of ice observing presents a somewhat similar picture. The most highly developed system is the Soviet, as is clear from a work on aerial ice reconnaissance by Karelin *et al.* (1946), and from a more recent book by Deryugin and Karelin (1954). The U.S. Navy Hydrographic Office has successfully developed its own systems (Bates *et al.*, 1954), in general designed for use by less highly trained observers than the Soviet. In the Baltic, where the problem is limited, a system based on rather different principles has been working effectively for many years. The main problems for the polar regions are how to make the best use of aircraft, together with the training of observers to work from them; how to collect the information speedily enough to be usable synoptically, and how to transmit it to the user

in his ship. This last is of course an extension of the problem of transmission discussed above. The whole problem has been under recent review by the Canadian Defence Research Board.

In very brief outline, that is the present position in sea ice studies. Wider knowledge of fundamental sea ice physics is now a cardinal need; the U.S. Navy Electronics Laboratory's program will help here, and one must hope that more of the recent Soviet work will become available. Recently initiated research at McGill University is another useful step. Ice probability studies should be made for all regions to which ships may be required to go, and in such a way as to reflect past records as faithfully as possible in order to get the greatest value from them. Ultimately, perfected forecasting techniques will provide more reliable answers to some of the ship navigator's questions; but probability studies will retain their usefulness as aids to the broad planning of shipping movements. On the synoptic side, there is an urgent need for more exact knowledge of the factors controlling the movement of floes. North American progress in this field appeared in 1954 to have reached the level achieved in the U.S.S.R. in 1939. Organization of the collection of observations and the dissemination of information must go forward on the basis of extensive use of facsimile reproduction.

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LIMNOLOGY IN THE NORTH AMERICAN ARCTIC AND SUBARCTIC*

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LIMNOLOGY, the physical and biological study of inland waters, is a comparatively new field and perhaps for that reason it has lagged somewhat during the recent studies of arctic resources. It may be agreed that limnology began about 1870 with Forel's studies in Switzerland. The early work was mainly in temperate areas, first in Europe and later in America. Studies of alpine lakes have resulted in notable contributions to the science as have also several expeditions to tropical lakes, but as yet very little has been done in the Arctic. An examination of the scattered results from arctic work and a survey of the potential areas for study, suggest that freshwater research in the Arctic should prove fruitful in both practical and theoretical fields.

Boundaries of the arctic and subarctic regions have been suggested and redefined by various geographers, climatologists, and plant ecologists. In general the search has been for a mathematical expression of climatic conditions which will produce a line following closely the boundary between forest and tundra. Köppen's (1908) line, joining points where the mean temperature during the warmest month is 10°C, has been improved on by Nordenskiöld's formula (1928) and again by Thornthwaite's line for 33 cm. evapotranspiration (1946). For our present purposes the Arctic can be defined as equivalent to the tundra and arctic icefields. The boundary between forest and tundra is thus the northern limit of the Subarctic but the southern boundary of the Subarctic is more difficult to define. Again, for our purposes we will use Subarctic to mean that northern, thin portion of the boreal coniferous forest, often referred to as transitional forest, open lichen-woodland, forest-tundra, or subarctic woodland, although the proponents of these terms would not consider them equivalent.

The field for arctic limnology

The number and extent of lakes in the North American Arctic is not widely appreciated. An examination of the arctic (tundra) region on the recent 100 mile-to-the-inch map of Canada shows 10 lakes between 500 and 2,200 square miles in area, 40 lakes from 100 to 500, and about 200 lakes between 25 and 100 square miles. Air photographs of the Arctic reveal hundreds of thousands of small lakes which cannot be shown on small-scale maps. It is obvious also, that the many rivers of the Arctic offer important possibilities for limnological investigation.

*Reprinted from *Arctic*, Vol. 6 (1953) pp. 198–204.

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Beginning at the west, the arctic lakes of Alaska and the Yukon are mostly small and located in the coastal plain. The District of Mackenzie has a number of arctic lakes and the huge Great Bear Lake close to the arctic boundary. The District of Keewatin has many lakes large and small, with Dubawnt and Baker lakes at its centre. In the Ungava Peninsula of northern Quebec there are numerous arctic lakes including the very deep Crater Lake in the great Ungava crater[1] which has attracted recent attention. Among the most interesting and least known of our arctic lakes are those on the islands in the District of Franklin. Victoria Island has a number of sizeable lakes and Baffin Island has at least 25 including Amadjuak Lake, 1,200 square miles in area, and Nettilling Lake, 2,200 square miles, in which the ringed seal, *Phoca hispida*, is found (Soper, 1928). These large lakes should certainly be investigated by limnological expeditions. The Subarctic is equally well supplied with lakes and in this area are found such great bodies of water as Great Bear Lake and the East Arm of Great Slave Lake.

Practical interest in the fresh waters of the Arctic centres naturally in their use for transportation and their possibilities for fish production. In the past the rivers were the important travel routes and more recently the lakes have provided convenient landing areas for float planes. Unfortunately little use has been made of these landings to examine the lakes. It has been suggested that arctic lakes are relatively unproductive of fish, but this opinion is by no means universal. Many rivers produce important quantities of arctic char.

Arctic lakes are of scientific interest in a variety of ways. A study of regional limnology in the arctic area might do much to clear up several problems of lake classification. The fauna of arctic lakes is of special interest in zoogeographic studies, especially in relation to the problem of relicts and glacial history. Perhaps the most fundamental problem is that of the physical and chemical conditions involved in the productivity of arctic lakes.

Past and present studies in arctic limnology

Many useful observations on the limnology of arctic fresh waters can be culled from general accounts of surveys or exploration and from technical reports in various scientific fields. Thus Porsild (1945 and elsewhere) provides useful notes on the small lakes in the Mackenzie delta and Eskimo Lakes basin and records a brief examination of Yathkyed Lake (1936). Soper (1928) explored parts of Nettilling and Amadjuak lakes on Baffin Island. However, studies which are primarily limnological are rare in the North American Arctic[2] and relatively few in the Subarctic.

Recent studies of the small arctic lakes in the Alaskan coastal plain have been concerned with a variety of problems, for example, orientation (Black and Barksdale, 1949), ice conditions and lake formation (Hopkins, 1949; Stone, K., unpubl.), lake history from pollen analysis (Livingstone, unpubl.), algae (Croasdale, unpubl.), and productivity (Comita, unpubl.). Far to the east, in Ungava, some freshwater investigations have been initiated by Dunbar

[1]Now officially named New Quebec Crater, sometimes referred to in the past as "Chubb Crater".

[2]Since this paper was written several studies have been carried out in the Alaskan Arctic. *Ed.*

(1951a) in addition to his important marine studies. In 1951 Martin (unpubl.) made interesting observations on Crater Lake, also in Ungava. Between these widely separated localities lie the Northwest Territories in which there appears to be no current project on arctic lakes.

In the Subarctic, mention should be made of the pioneer work on Karluk Lake, on Kodiak Island, Alaska, by Juday and others (1932). This was the first intensive limnological study in the far north of America though Bachmann's work in Greenland dates back to 1908. Teslin Lake, on the Yukon–British Columbia boundary was investigated by Clemens and others (1945). Great Bear Lake was surveyed by Miller and Kennedy in 1945, as reported by Miller (1947). My own work on Great Slave Lake (1950) is of some interest in this connection although only the East Arm should be regarded as in typical subarctic surroundings. Clarke (1940) and Bardach (1952, unpubl.) have provided information on lakes in the Thelon region, east of Great Slave Lake, and Harper (1948) has reported on Nueltin Lake just north of the Manitoba boundary. Thus a modest beginning has been made in the limnological investigation of the Subarctic, a situation which might suggest that new work in the near future should be concentrated on lakes in the Arctic proper.

Possible contributions from arctic limnology

The investigation of arctic lakes should contribute to the solution of some basic problems in limnology. Forel's early classification distinguished as polar, those lakes in which the surface temperature did not rise above 4°C. This polar type and certain subdivisions which have been suggested, are not much used by limnologists. Most of the lakes in the Subarctic would be classified as "temperate" under the Forel system. Knowledge of deep temperatures as well as surface, and of water circulation is needed in order to arrive at a satisfactory thermal classification. At the present time we lack not only information on water temperatures, but even data as to the usual dates for open water in many of our arctic lakes. Tyrrell (1909) suggested that Dubawnt Lake was always more or less completely covered with ice at the end of last century. However, Porsild (1936) reports Yathkyed clear of ice at the end of July, also that large lakes on Banks and Victoria islands were ice-free by mid-August in 1949 (1950). Soper (personal communication) reports that Nettilling and Amadjuak lakes on Baffin Island are usually free of ice about the beginning of August and remain open for a maximum of two and one-half months. Small shallow lakes are free of ice much earlier in the season.

The trophic classification of lakes is probably of greater interest than the thermal since it is more closely related to productivity. Extremes of low temperature might be expected to impose a degree of oligotrophy on most of the lakes in an arctic area. Livingstone (1951, unpubl.) mentions Chandler Lake, in the Brooks Range of northern Alaska, as very oligotrophic. However, Andersen (1946) found lakes in northeast Greenland which were moderately eutrophic in spite of a very short summer season and low temperatures. He also records severe winter stagnation during the long period of ice cover.

The innumerable shallow lakes and ponds of the Arctic are often described as teeming with cladocerans, phyllopods, insect larvae, and worms. Apparently these should be regarded as eutrophic. Their surface temperatures may exceed 15°C and can reach this within a few days of the disappearance of the ice. Many small ponds freeze to the bottom in winter and have no inlets or outlets so they are lacking in fish. Johansen (1922) refers to a lake near Bernard Harbour with a maximum depth of 20 feet and an ice thickness of "almost ten feet". In this lake he found trout (*Salvelinus*) and sticklebacks. Even in lakes lacking fish the great production of invertebrates may be of importance to man, since it attracts many species of shore birds and waterfowl.

Water circulation is probably complete during the open water season in the many shallow arctic lakes. Little is known about circulation in deep arctic lakes. However, Martin (personal communication) reports that on 31 July 1951 Crater Lake was homothermous at 2.55°C from 10 to 135 metres depth. The surface temperature was 2.9°C. Unfortunately no analysis was made of deep-water oxygen but such homothermy suggests the probability of deep mixing. The total solid content of a sample of lake water contained approximately 15 p.p.m. of which approximately one-third was organic material. Interesting cases of meromixis (incomplete circulation) are found in coastal lakes which have at some time received salt water. Johansen (1911) reports this condition in Sælsøen in northeast Greenland and Dunbar has recently investigated a similar situation in Ogac Lake, at Ney Harbour, Frobisher Bay.

It will be of interest to compare the productivity of arctic lakes with that of arctic marine waters. The standing crop of plankton in truly arctic marine waters is low, presumably because of temperature. In nearby subarctic waters it may be from three to six times as great (Dunbar, 1951b). Is there a similar difference between the productivity of arctic and subarctic fresh waters? Clarke (1940) expresses the opinion that although arctic lakes may appear to have heavy fish populations, they will not support much fishing because of the short season and slow growth of fish. However, Kennedy (1953) finds that the scales of whitefish of Great Slave Lake show nearly half their growth during the first two weeks of August. This very rapid growth in the short season allows the population to support a very extensive commercial fishery. The ice on small arctic lakes melts early and allows a rich growth of plants and animals. In the larger lakes of the far north the ice cover lingers reducing the potential growth period for plankton.

The progressive warming of northern areas has caused a great increase in the fish production of northern marine waters, for example the increased cod production in the Greenland area. It would be of interest to discover whether the fresh waters of the Arctic are undergoing a similar change in productivity.

Arctic and alpine areas have much in common and we are in the habit of speaking of alpine–arctic conditions. The extent to which this resemblance is shown in lakes should be investigated. Arctic lakes are exposed to very different light conditions and, in general, to much lower precipitation than are the high alpine lakes of temperate latitudes.

Zoogeographic studies in the North American Arctic have been concerned mostly with marine organisms. Information as to the distribution of some freshwater invertebrates is presented in the various reports of the Harriman Alaska expedition, the Canadian Arctic expedition, and in many miscellaneous papers. Wynne-Edwards (1952) has provided an excellent summary of the present knowledge of freshwater vertebrates (excluding the birds) of the Arctic and Subarctic. However, the fauna both vertebrate and invertebrate, of the inland lakes of arctic America is still largely unexplored.

Some suggestions for limnological research in the Arctic

It would appear that in the past little consideration has been given to the need for research in arctic limnology. The program of desirable scientific investigations in the North American Arctic, prepared by the Arctic Institute in 1946, makes no reference to limnology, although it deals in some detail with numerous fields of biology. In 1950 the First Alaskan Science Conference urged wildlife research and the investigation of water supply, vegetation, etc., but again the report makes no reference to limnology.

Assuming that the good beginnings in Alaska and in the Ungava–Baffin areas are to be continued and expanded, it would seem that we should begin at once to fill the great gap which lies between. Much information has been obtained concerning arctic lakes in Greenland (various authors publishing in *Meddelelser om Grønland*) and in northern Norway (e.g., Strøm, 1934). Important fundamental studies are being carried on by Ekman, Rodhe, and others on arctic lakes near the laboratory at Abisko, in Swedish Lapland. Vibe (unpubl.) has been working for several years on the freshwater fauna of southwest Greenland. Thorson (1946) urges the extension of ecological studies of fresh water in the high Arctic and makes special reference to the problem of oxygen supply under the ice of lakes. We do not know the extent to which these findings may apply to lakes in northern America.

A broad attack on the problem might be made by equipping one or two parties for a reconnaissance of lakes in the Canadian Eastern and Western Arctics. Such a program might be worked in conjunction with other surveys or investigations in order to share the costs of transportation. The itinerary could be quite flexible since the whole area is practically unknown from the limnological point of view. Two or three summers of this kind of work should provide invaluable data as to depths, temperatures, chemical, physical, and biological conditions, and the distribution of aquatic organisms.

More intensive investigations might be started at once in a few selected arctic lakes, differing in areas and depths and located possibly in the District of Keewatin, as the centre of limnologically-unknown territory. Studies of these lakes should continue through the open-water season and any opportunity for winter sampling should be seized since some of the more important problems can be solved only by knowing conditions under the ice. It should be made clear that while faunistic studies can be advanced by casual and irregular collecting, real progress in limnology can be expected only as a result of continued and intensive studies.

It was suggested above that the Ungava work should be continued and expanded. One of the more obvious needs is a study of the freshwater fauna of the Ungava-Labrador Peninsula. Such an investigation would determine the northern limits of temperate species and might demonstrate the effect of height of land as a factor in distribution. It would be of particular interest to see whether any zonation observed in freshwater organisms agreed with the plant cover classifications proposed for this area by Rousseau (1952), Hustich (1949), and Hare (1950).

An arctic river should also be selected for careful study of its physics, chemistry, and biology. The river chosen should have a good population of that important fish species, the arctic char. A preliminary study of the char was made by Sprules (1952) near Chesterfield Inlet, and a second by Grainger (1953) in Frobisher Bay, south Baffin Island. Further study might be made in a stream in the Western Arctic with comparative observations on a land-locked population. General studies of the distribution of freshwater fish in the Arctic are much needed.

It would seem that, if workers in different fields of arctic investigation would make known their needs, they might cooperate in obtaining vital information. Perhaps plant ecologists, geologists, and others might be willing to record depth and temperatures and to take samples of plankton if suitable equipment were provided. In return, limnological field parties might collect specimens and obtain seasonal data in botanical and meteorological fields. An excellent illustration is provided by Porsild (1932). In the spring of 1928, while engaged in botanical studies, he observed and made accurate measurements of seiches under the ice in the Dease Arm of Great Bear Lake.

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ARCTIC AND SUBARCTIC MARINE ECOLOGY: IMMEDIATE PROBLEMS*

M. J. Dunbar†

THE study of marine biology in the north has been pursued, in the past, mainly by the Scandinavian countries. In the northern waters which Scandinavian biologists do not normally visit, and especially in the North American Arctic, marine investigation is in its infancy, and has even lagged behind terrestrial ecology in the same area. As there are now signs that this condition is to be put back in balance, this is the proper time to review briefly the most interesting results of the past and to point out the most promising fields of study for the immediate future.

For the purposes of this paper the terms "arctic" and "subarctic", applied to the marine environment only, are used as defined previously (Dunbar, 1951a): the marine arctic being formed of those areas in which unmixed water of polar origin (from the upper layers of the Arctic Ocean) is found in the surface layers (200–300 metres at least). Admixture of water of terrigenous origin is ignored in this definition. The marine subarctic is defined as those marine areas where the upper water layers are of mixed polar and non-polar origin. By far the greater part of the marine subarctic lies on the Atlantic side, extending from the Scotian shelf and Hudson Strait to the Barents and Kara seas, and including almost the whole coast of west Greenland, the waters around Newfoundland and Iceland, much of the Norwegian Sea, and the waters off the west coast of Spitsbergen. The southern boundary of the marine subarctic is the limit of southward penetration of the arctic water; clearly it varies seasonally and with the state of the climatic cycle. For the large and rather ill-defined marine region south of the subarctic, the term "boreal" is used here, but with that region we are not directly concerned. It should be added that the division employed here apparently applies less to sessile animals and plants, than to the plankton and nekton, because of local variations in summer. This does not disturb the general picture, and is discussed further below.

Production

The fact that this division between the marine arctic and subarctic is not an arbitrary thing, but reflects a real and obvious difference in the biological production of the two regions, points to this difference as one of the most interesting things about the northern waters, and the study of the causes of the difference has only just begun. The fact itself is quite evident: the great

*Reprinted with some additions, from *Arctic*, Vol. 6 (1953) pp. 75–90.
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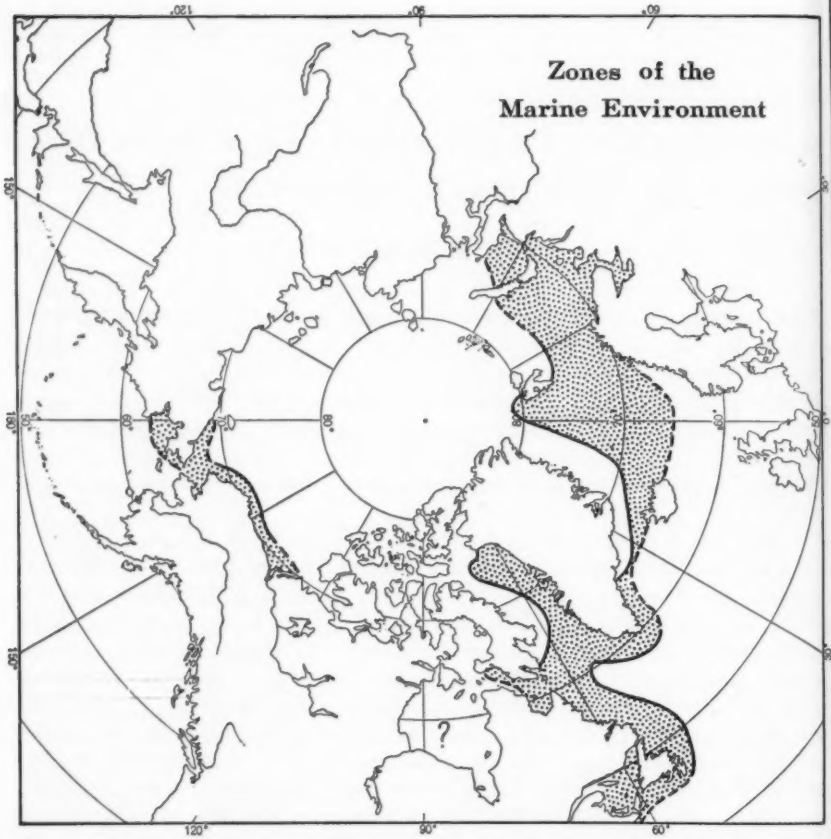

Fig. 1.[1] Zones of the marine environment; the subarctic zone, as defined in the text, is stippled. The lines of delimitation are approximate, and dotted lines indicate regions still in doubt. There is some evidence that the subarctic should extend farther south in the region southeast of Iceland, northern Scotland, and western Norway, and that the coasts of Kamchatka and parts of the Seas of Okhotsk and Japan should also be included in the subarctic.

subarctic belt across the North Atlantic area is one of the richest parts of the oceans of the world, the home of fisheries of immense value, maintained by many nations of the Atlantic community. That these fish resources are dependent upon plankton production is obvious, and the same is true of other parts of the seas of great economic value, such as the subantarctic belt and the region of influence of the Peru Current off the west coast of South

[1]Figures 1 to 4 are reproduced from drawings prepared for the author's chapters on "Northern Waters" in the volume 'Geography of the Northlands', edited by G. H. T. Kimble and Dorothy Good, published for the American Geographical Society by John Wiley and Sons (1955).

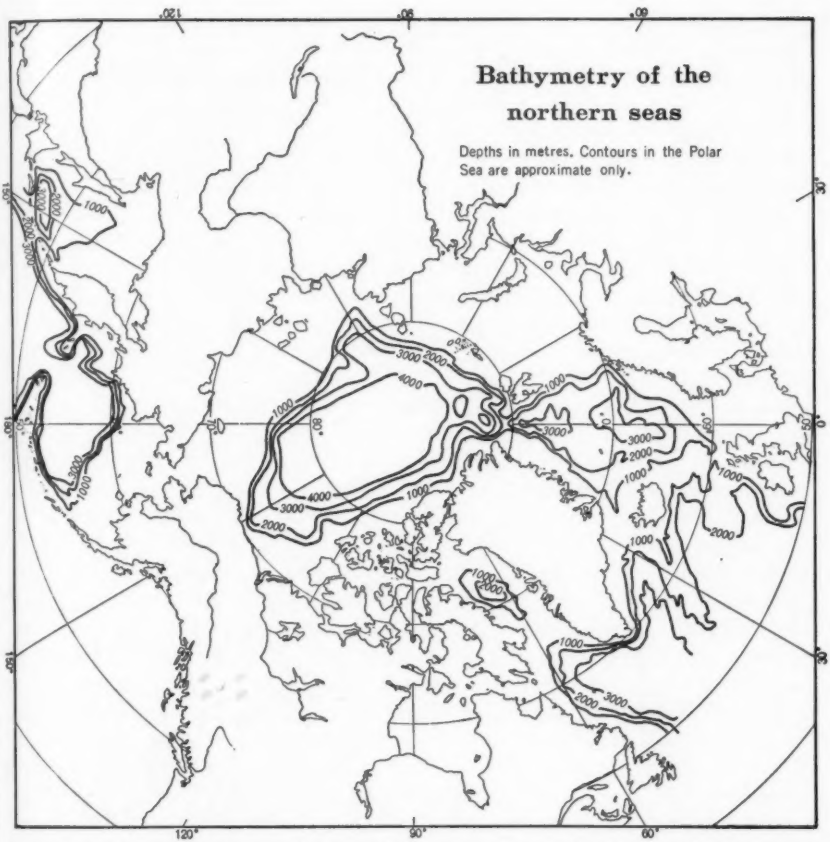

Fig. 2. Bathymetry of the northern seas.[1] The four deep enclosed basins (Arctic Ocean, Greenland and Norwegian seas, and Baffin Bay) have many faunistic points in common, although separated by submarine ridges. Notice the Wyville Thompson ridge north of Scotland and its extension to Iceland and east Greenland, also the similar ridge in Davis Strait. Both ridges rise to a water depth of about 600 metres.

America. In fact the much higher plankton production in the subarctic, when compared with the arctic, is at once apparent in the field. The quantitative measurement of this difference in production, however, is only now beginning in certain parts of the north, and is one of the next steps to be taken in the North American Arctic and Subarctic. The chemical and physical factors underlying the differences in production have also to be investigated. It may be that the high production in subarctic water is caused

[1]This paper was written before the preliminary publication of the Russian discovery of the Lomonosov Range across the floor of the Arctic Ocean from the Novosibirskiye Ostrova to the north coast of Ellesmere Island.

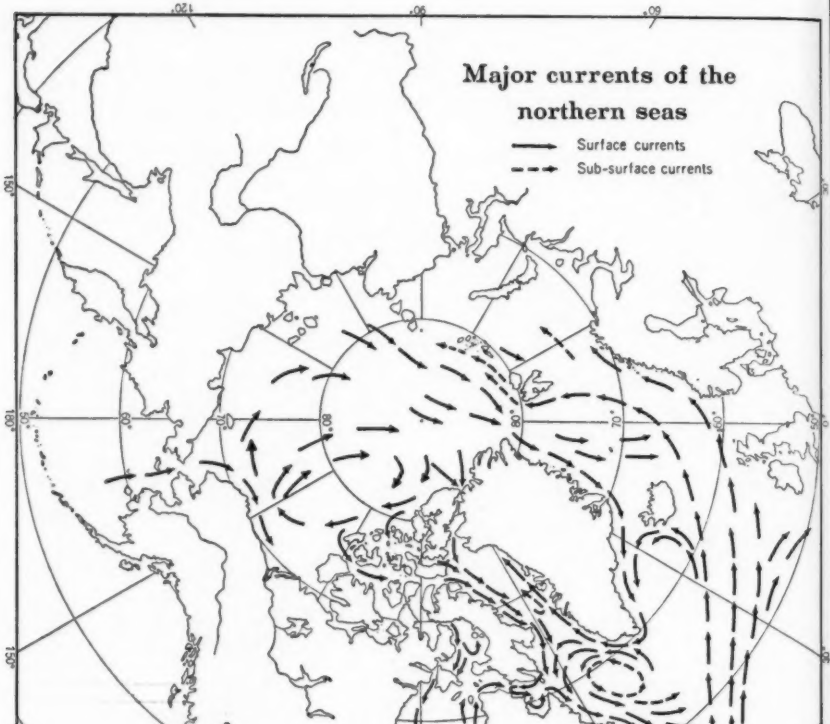

Fig. 3. Major currents of the northern seas. All details, lesser eddies etc., omitted.

simply by the lifting of the temperature inhibition in water of arctic origin (arctic water being very cold, and therefore presumably a depressant upon growth rates[1]), which is otherwise of high production potential in such properties as gases held in solution, nutrient salts, and high viscosity; but this has still to be demonstrated. It has also been suggested that the presumed high concentration of polymerized water molecules (trihydrol or higher

[1]It has been demonstrated that the growth rates of the larvae of certain bottom-living forms in the arctic and subarctic are in fact no lower than in similar species in warmer water, indicating presumably a genetically established regulating mechanism, but for the mass of the zooplankton, and for the phytoplankton, there is as yet no evidence of this. In fact, the much larger generation time in colder water in the holoplanktonic animals, indicates a greatly reduced rate of growth, as has been found in marine copepods at Scoresby Sund by Digby (1953). For the pelagic larvae of benthonic species there are other pressing considerations which favour the selection of the higher growth rates, and which do not apply to the holoplanktonic forms.

polymer) in water recently melted from ice may have a beneficial effect upon the growth and division of plant cells, as has been demonstrated experimentally. So far no method of measuring the concentration of specific water polymers has been devised.

There is another possibility in this matter of subarctic production which requires testing, namely that the high production is caused entirely by upwelling of water from lower layers, laden with plant nutrients, at all times of year. Thus the underlying cause of the high production in the Icelandic waters, and in the vicinity of the Faeroes and northern Scotland is, on this view, the presence of the submarine ridge (Wyville Thompson ridge), running from Scotland to the Faeroes, and extending from there to Iceland and east Greenland, causing upwelling of Atlantic water. The ridge between Holsteinsborg and southeast Baffin Island is supposed to play the same part in southwest Greenland. High production in the subarctic belt is thus looked upon as strictly comparable to the high production along the west African coast and the west coast of South America, although the types of water upwelling are markedly different. In the latter two regions it is cold antarctic water which comes to the surface, whereas any upwelling in the Iceland–Scotland area must be of Atlantic water. Again, it may be that the mixture of polar and non-polar water causes general instability, favouring vertical exchange of water, and that this is the important thing in determining subarctic production. It is of course clear that upwelling, wherever it occurs, will normally increase production, as it does everywhere in the usual annual succession of events. But it is still doubtful whether upwelling alone can explain the high subarctic production; it is significant that wherever arctic water meets boreal water, the production goes up. Moreover, it is by no means demonstrated that instability in subarctic waters is the rule; there is high stability, for instance, in the west Greenland coastal current in summer.

Quite apart from further hydrographic work designed to show the stability or instability of subarctic waters, and the extent of upwelling, the measurement of the phosphate and nitrate concentrations in both arctic and subarctic water should go far towards elucidating this interesting matter, the discussion of which dates as far back as Nansen (1902) and Gran (1902). The problem was attacked by Braarud (1935) in Denmark Strait and the east Greenland current, but it is not yet quite clear to what extent the supply of plant nutrients in the surface layers is exhausted during the phytoplankton bloom, and how soon it is replaced. It is quite possible that the phosphate is not exhausted in the arctic water in the spring, and that the arctic water may always have a significant surplus of phosphate and nitrate to contribute to the subarctic, even in summer.[1] The Russian Papanin expedition of 1937 found that although the phytoplankton growth in the Arctic Ocean in July was poor, there was considerable flowering in August, by which time the snow cover had melted and the penetration of light became possible. The presence of considerable

[1]Measurements of phosphate by the *Dana* expeditions of recent years have shown low values, down to zero at the surface in July, in east Greenland. Measurements made by the *Calanus* expedition, however, in Cumberland Sound, Baffin Island, show somewhat higher values and the *Godthaab* results were variable. The question is by no means settled.

quantities of phytoplankton beneath the ice in summer is also recorded from Point Barrow (MacGinitie, 1949, personal communication). If the use of the plant nutrients occurs so late in the season in the Arctic Ocean, it may well follow that the outflow of nutrients in the east Greenland current and through the Canadian Archipelago in the spring is quite large.

The measurement of the amount of plankton can be done in several ways. The number of plant cells can be counted directly from samples collected in water samplers and preserved in weak formalin, a method which was used by Gran (1929) and by Braarud (1935), and which is at present being employed by Grøntved (1953, personal communication) on samples from west Greenland, with good results. The zooplankton, excluding the largest members, is measured by the use of vertical nets, or by quantitative mechanical sampler. Both these methods measure the "standing crop", or concentration of organisms at a given time, and they are reliable if enough samples are taken. Chemical methods, measuring the consumption or production of a given element of metabolism, provide an estimate of the rate of production; a recent innovation in this field is the Carbon-14 method developed by Steemann Nielsen (1952) and used on the *Galathea* expedition. All these methods should be applied to the North American Arctic and Subarctic.

There are particular areas where such study of the plankton production would be of special interest, such as Hudson Bay, the Arctic Ocean itself, and the Beaufort Sea. The latter, although strictly speaking a part of the Arctic Ocean, is nevertheless clearly influenced by non-arctic water from the Bering Sea. Hudson Bay is highly stratified in summer, and it has been supposed that the apparent low production of the Bay (which still has to be confirmed) is caused by the lack of proper vertical exchange of water during the winter. There are thus two points to be cleared up in Hudson Bay: the actual level of production of living matter, and the winter hydrographic regime. The latter can of course only be done by working stations through the ice, a technique which has already been tried out on several occasions: by the Danish Three Years expedition in east Greenland (1931–4), by the Papanin expedition of 1937, by P. Digby at Scoresby Sund, and by D. Nutt in the Goose Bay region in 1952. A technique of through-the-ice work is described and illustrated in Thorson's (1946) most useful paper on future work in arctic animal ecology.

The plankton production in the Arctic Ocean itself has been a matter of contention for many years, but it has never yet been measured. Nansen, after the famous *Fram* expedition of 1893–6, concluded that the Arctic Ocean was a barren area, because his plankton nets caught little plankton and the seal population seemed very low. Stefansson, on the other hand, having lived on seal during a prolonged trek across the polar ice during the Canadian Arctic expedition of 1913–18, obtained a quite different impression, and reported, moreover, the abundance of so-called "shrimps" (possibly a pelagic amphipod) in the surface water between the ice floes. The collections of the Russian Papanin expedition of 1937 apparently confirmed Stefansson's conclusions rather than Nansen's, although the final plankton results do not seem to have appeared yet. Clearly this situation calls for decisive study, and the only way

to do it is to maintain regular quantitative plankton collections all year round at one station, chosen for ease of access and depth of water. Probably the coast of northern Ellesmere Island, or of Greenland, offers the best conditions. The penetration of light at all seasons of the year, and the oxygen and phosphate concentrations, should of course be measured at the same time.

Before leaving the subject of production, mention should be made (1) of the necessity for study of winter as well as summer conditions in all phases, both in those areas normally frozen over, and in the ice-free subarctic regions of southwest Greenland, and (2) of the need for bacterial studies in northern seas, in order to establish the rate of bacterial mineralization of organic detritus.

Plankton biology in general

There are other facets of plankton biology in cold waters which offer valuable returns for research, but which can be mentioned here only in summarized form:

(1) Vertical diurnal migration of the plankton, a normal phenomenon all over the world and largely dependent upon changes in illumination, was observed in Svalbard waters, latitude 80°, in 1893 by Walther, even in the height of summer when the sun was well above the horizon at midnight. Walther was surprised to find this phenomenon so far north in summer, but Russell (1927) has since pointed out that the illumination which is able to penetrate the surface at that latitude in June, at midnight, is very much less, midnight sun or no midnight sun, than the penetration at noon. Later, however, Bogorov (1946) published his observations in the Barents Sea, in which he found no evidence of vertical migration during the height of summer. Clearly this problem needs further research.

(2) Cold-water plankton is remarkable for the large size attained by the individuals, when compared with the same or closely related species in temperate or warmer waters. It has been assumed that the effect of the low temperature on the development of the gonads is one important factor: "Delayed sexual maturity, which favors growth in size, appears to be directly dependent on retardation of growth at lower temperatures, and this is a common characteristic of northern marine creatures" (Hesse, Allee, and Schmidt, 1937, p. 159). It is not yet clear, however, why the gonadial growth does not maintain the same rate, relative to somatic growth, as in warmer water. It may be that so much energy is required to offset the very low environmental temperatures that the gonads are penalized in favour of the general metabolism. Large size is an advantage at low environmental temperatures, for poikilotherms as for homoiotherms, but in poikilotherms it requires a longer life to achieve it (relative to the size of the species), because growth rates are controlled by the environment (*see* footnote p. 216); the adjustment of the gonadial and somatic growth rates may therefore be established in the hereditary mechanism of the species, and may not be simply and directly controlled by the external temperature. At all events, in order to throw light on this perennially puzzling matter, an investigation of the metabolism

of arctic plankton animals is needed. The measurement of the oxygen requirements of arctic plankton can be done in an adequately equipped ship's laboratory, but more simply in a shore station. The results would dovetail usefully with the work of Thorson (1936), who studied the oxygen metabolism of shallow-water benthonic forms, mostly molluscs, in northeast Greenland, and found that the metabolic rate was approximately the same as in closely related temperate (Danish) species and in tropical species, each group being measured at their normal environmental temperatures. Measured at the same temperature, the arctic forms showed a considerably higher metabolic rate. Such remarkable metabolic regulation was not found in a variety of arctic aquatic forms by Scholander *et al.* (1953). The whole matter of body size and metabolic rate has recently been reviewed, with considerable new experimental work, by Zeuthen (1947), and a theoretical development of the question has been published by Hemmingsen (1950).

(3) Thorson (1946, p. 25) mentions the food of zooplankton in the north as requiring research. To quote one point from his paper: "Ussing [1938] is of opinion that in winter most copepods [in east Greenland] are able to live on the food obtained in summer (stored as oil drops). Place, therefore, such winter-copepods in sterile sea-water to have this problem cleared up." This work, together with the metabolic study already mentioned and other research discussed below, needs wintering parties with laboratories equipped with constant temperature aquaria, filtering devices, and so on. Laboratories aboard research vessels, even small vessels, should also be similarly equipped if possible.

(4) Breeding cycles of planktonic animals, the nature of which is fundamental to the production of the standing crop each year, require a great deal of study, and for best results also call for winter as well as summer work. The fact that interesting complications arise in the breeding cycles of certain zooplankters in the north has already been demonstrated by Dunbar (1941). Generation time in certain copepods has been studied by Ussing (1938), and the bimodal size-distributions in copepods found in northern waters by Ussing and by Jespersen (1934) are also involved in this matter of breeding cycles. The suggestion of Ussing that the surface water of fjords, which is warmed in summer time and which has been called "fjord water" by the Danish workers, is important and perhaps essential to the survival of arctic copepods, requires testing.

Benthonic and littoral fauna

Many benthonic and littoral animals are sessile, and all of them, except the fishes, are limited in powers of locomotion and dispersal. Most of them, moreover, are restricted in their distribution with respect to depth. These circumstances make it less simple to follow the arctic–subarctic pattern of distribution in the benthos and littoral than in the plankton and nekton. Large-scale changes in the position and extent of the subarctic marine belt will of course result in extinctions of sessile populations and their replacement by others, but at any time during this climatic cycle there will always be seasonal differences in temperature in the upper 30–50 metres of water, which will greatly affect the distribution and living conditions of these forms. This has

been pointed out and developed in a very interesting manner by Lemche (1941), for the opisthobranch gastropods of east Greenland. Forms of more southerly affinities are found in northeast Greenland in the upper waters only, where reproduction can take place at less rigorous temperatures in the summer. Below this zone there is a population of arctic forms which live at the lower temperatures all year round. Consequently, if the distribution of the two groups are placed on the same map without taking depth into account, they are found to coincide almost exactly in east Greenland. This of course is quite misleading, and emphasizes the fact that for the division of the benthonic fauna into arctic and subarctic regions it is essential to allow for this differentiation within the upper water layers. (The criterion employed, described above, deals with the upper 200–300 metres of water, which is the approximate depth of the arctic water layer in the Arctic Ocean; below this the depth factor applies also, naturally, to the plankton). So far, no work of this sort has been done on the North American Arctic shallow-water benthos.

The distinction between the two groups just mentioned lies in their reproductive physiology, and there is no doubt that the most promising lines of research in this ecological division lie in the elucidation of the reproductive requirements and limitations. Gunnar Thorson, of the University of Copenhagen, has made notable advances in this field, and since he has already reviewed the whole subject on a global scale (Thorson, 1950, 1951), and also established the study in arctic waters (Thorson, 1936) and indicated the points which require research in the immediate future (Thorson, 1946), it is not proposed to deal with this subject here. It must be enough to point out that a valuable contribution to the whole pattern of benthonic reproductive habits, which are of great interest, would be made by applying Thorson's methods to the North American fauna, particularly as regards the presence or absence (and length) of the larval life. There is also much work to be done on the density of the benthonic fauna, by the use of bottom samplers, along the lines of Vibe's (1939) work in the Thule and Upernavik districts. It might be added here that the questions raised by the now classical work of Orton (1920), concerning the factors determining the onset of maturity in cold water, and the time of breeding, have not yet been settled.

The term "littoral" is used here as coextensive with "intertidal", and thus not in the sense advocated by Hesse, Allee, and Schmidt (1937). The littoral fauna has special conditions to face, in which the atmospheric climate must play an important part. It was upon the marine climate, however, not the atmospheric climate, that the study of Madsen (1936, 1940) put the emphasis as possibly determining the distribution of northern littoral faunas. His work suggested that the littoral fauna in large part disappeared north of a point which was determined by the nature of the water, possibly by the presence or absence of Atlantic water on the coast. This point would thus coincide with the boundary between the arctic and subarctic regions as defined in this paper, and hence the nature of the littoral fauna might serve as an added indicator of hydrographic conditions. Before this possibility can be developed, a great deal of littoral collecting is necessary, especially in the North American Subarctic.

Apart from such zoogeographical considerations, the littoral fauna of the northern seas calls for investigation of breeding seasons and breeding cycles at different levels on the beach, and of the conditions of survival during the winter, on all of which points our knowledge is extremely poor. The biology of such abundant forms as the amphipod crustacean *Gammarus* (several species), the barnacle *Balanus balanoides*, and the snail *Littorina saxatilis*, for instance, has scarcely been studied at all on arctic and subarctic shores; and almost nothing is known of the northern littoral microfauna.

Nekton (fishes and marine mammals)

It is in the study of the macrofaunal elements of the northern seas that we come into immediate contact with the economy of the Eskimo, and it is here that investigations intended to develop new resources, or to conserve the old, become of immediate value. They are not on that account necessarily the most important in the long run, but they appeal to the general public, and hence reach more easily for the public purse-strings than the more obscure scientific projects can hope to do.

In true arctic waters, that is, inside the arctic zone as here defined, fishes are not abundant, and the nektonic constituent in the biomass is dominated by the mammals; in the subarctic waters, fishes make up a very important part of the total fauna, and the mammals are not dominant. This interesting fact, which has as a corollary the direct dependence of the mammals, in the arctic zone, upon the macroplankton (invertebrate) instead of on the fish, has never been explained, nor has there been any attempt to throw light upon it experimentally. Speculation upon it leads to a consideration of the glacial history of the northern waters, and of the time-scale in the evolution of fishes, and although the problem of the glacial history can be attacked in various ways through the study of northern marine ecology today, it is not the purpose of this paper to develop this line of thought. It has been touched upon in another paper (Dunbar, 1951b).

The problem can also be attacked, more directly, by the study of the metabolism of arctic fishes at the temperatures at which they live, and of the general relation which their reproduction and development bear to temperature. It should be emphasized that the poverty of the fish fauna, in terms of numbers of fish species, is not itself surprising—it is part of the general picture of fewer species of most groups in arctic water.[1] What has to be explained is why no

[1]A recent study (Thorson, 1951) has thrown a new light on the matter of species numbers in the marine environment of the arctic, temperate, and tropical regions. For the intertidal and shallow-water invertebrates, it is the "epifaunal" species which increase greatly in numbers toward the tropics, the "epifauna" including all dwellers upon the surfaces of various substrates, such as rock, stones, coral reefs, and seaweed, whereas the numbers of species in the "infauna", mainly burrowing forms in the large uniform environment of sandy and muddy bottoms, are approximately the same in comparable environments in all three major zones, tropics to arctic. In the light of this, the poverty of fish species (and also of holoplanktonic species) in the arctic water appears to be a breach of the rule, for ecologically the fishes, especially the pelagic fishes, must be compared with the benthonic and littoral "infauna", for which the environment is constant over large areas, and not broken up into a multitude of small habitats as in the epifaunal environments.

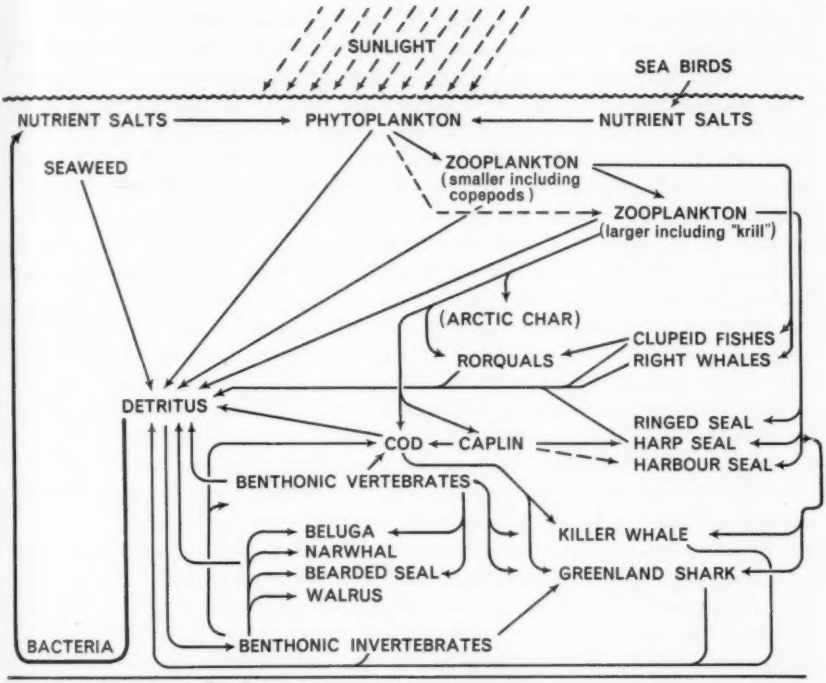

Fig. 4. The biological cycle in the arctic and subarctic marine zones, somewhat simplified. The prey–predator system illustrated in the right-hand three-quarters of the figure ends finally in the production of organic detritus, which is decomposed by bacterial action mainly on the sea-floor in moderate depths. The resulting supply of inorganic plant nutrients (nitrates, phosphates) is returned to the surface by vertical water exchange in the autumn and winter, and is thus available for the regeneration of the phytoplankton population in the springtime conditions of increasing sunlight.

single species has been able to achieve a dominant or even an important position in the total fauna, in contrast to other poikilotherms, all of them invertebrates, many of which are extremely abundant in arctic water, such as certain amphipods, copepods, and molluscs.

The poverty of the fish fauna in arctic water is particularly remarkable in the pelagial, as opposed to the littoral and benthal, regions. The polar cod, *Boreogadus saida*, although frequently referred to as a pelagic form because it is often seen among ice floes, is in fact much more commonly found close to the bottom in fairly shallow water; and the arctic char, *Salvelinus alpinus*, although in part a planktonic feeder during its short annual stay in salt water, cannot be considered a true pelagic species on that account. The shallow water benthos includes a few families of fishes which are widespread although nowhere very abundant. The young of these benthal forms, Cottids, Liparids, Agonids, Gadids, etc., are often taken in plankton nets, especially at night, and

it is probable that much more could be learned about their abundance and their habits by the use of large (two-metre) stramin nets, and other types of small-mesh mid-water trawls. Pelagic young fish escape, for the most part, from the ordinary plankton nets. The same is true of the largest pelagic crustacea, such as the Hyperiid amphipods and the Euphausids which, like the young fish, lie on the border-line between the plankton and the nekton, and which can be collected adequately only with appropriate mid-water trawls.

The subarctic fisheries must be left out of the present paper; they are an extremely large subject in themselves. Moreover, they are being studied and developed constantly, in such areas as west Greenland, Spitsbergen, and the Norwegian, Barents, and Kara seas. There is room for considerable biological work on the economic fishes of the Labrador coast, however, and the possibilities of the Beaufort Sea have yet to be investigated fully. At the northern edge of the subarctic water, and also beyond it, there is a need for experimental fishing for such forms as the arctic halibut, *Reinhardtius hippoglossoides*, and the Greenland shark, *Somniosus microcephalus*, in Baffin Island waters and northward. The breeding habits of the Greenland shark are still unknown. In the Burwell area of Ungava Bay the *Calanus* expeditions recorded the young of the arctic halibut, but the adults have not yet been taken.

In terms of man's immediate interests, there is an urgency about the scientific study of the arctic and subarctic marine mammals which does not apply to any other marine problem discussed here. The northern sea mammals have been hunted by Eskimo and by Europeans for centuries; the European killing has been for a shorter time, but has been very much more destructive. The Eskimo, by themselves and uninfluenced by Europeans, had struck a natural balance between themselves and their sea mammal resources. They were themselves part of an established ecological system. The commercial whalers and sealers, on the other hand, came from another system upon which they were dependent, and their activities among the northern sea mammals may rightly be termed an invasion. As might be expected, the species which they prized most, the Greenland whale or bowhead, was soon brought to the verge of extinction, and the introduction of the rifle to the Eskimo, by both whalers and traders, is now doing considerable damage to the seal populations. Whatever recriminations may be made about these two facts (the one is history, the other is now much more than a simple zoological problem), they have left problems which the zoologist can certainly tackle.

It is probably true that all marine mammal species in the north, at one or more points of their range, are now seriously reduced in numbers. There may be exceptions to this, for instance the white whale and the narwhal, which possibly are holding their own, but in general the marine mammal populations have been declining, and in a belated awareness of this, we are faced with the fact of our almost complete ignorance of the most elementary matters of their life histories. The cases of the Greenland whale and the walrus are particularly clear. Since the almost complete extinction of the bowhead before the First World War, it has been given protection, and there are signs now that the population has been very slowly increasing; for the present there is little to

do about it except to leave it in peace, and to keep records of its recovery. But the walrus is another matter; there is clear evidence that the walrus was once much more widespread than it is at present, and it is improbable that this retreat has been caused entirely by changes in climate during the last four hundred years, although that may have had something to do with it. The walrus has been the object of commercial hunting for several centuries, and it is still occasionally killed in numbers by sealing vessels. It is also hunted by Eskimo armed with rifles, some at least of whom seem to have forgotten their fathers' hunting wisdom, so that there is much waste, especially in summer, which would not have occurred in earlier times, and without the rifle. The same is true of other Pinnipedia in the north. The sinking during the summer hunting, caused by shooting the animals from a distance, very often without adequate means of retrieving them, accounts for the wastage of a ridiculously large proportion of the seal and walrus. It would be a mistake to think that this matter does not come into the business of the marine biologist. The Eskimo is part of the marine system, just as the whaler is, and his activities are most important zoologically. In this connection, the designing and introduction of a good, inexpensive shoulder harpoon gun would be helpful.

We have to make a study of the life histories of the marine animals, beginning from almost nothing, in order to discover where we may apply conservation measures. A little has been published on the walrus, from Alaska (Collins, 1940) and from northwest Greenland (Vibe, 1950), but for the rest we have only scattered observations published in odd corners of expedition reports, popular books, or filed in manuscript in Government offices. There is an excellent account of the harp seal (*Phoca groenlandica*) of the White Sea area by Sivertsen (1941), and Fisher (1952) is conducting a thorough study of the harp seal on its Gulf of St. Lawrence breeding ground, sponsored by the Fisheries Research Board of Canada. The harp seal, like the hooded seal (*Cystophora cristata*), is a migrant species, spending the summer in the north. Those which breed in the Newfoundland and St. Lawrence area move to west Greenland and Baffin Bay in the spring, and they are fairly common in Ungava Bay and along the eastern and northern coasts of Baffin Island. It is in this northern part of the harp seal range that we need information on abundance, food habits, and migration. It is possible that some of the adolescent seal remain in the north during the winter; if so, it is important that we have some estimate of the numbers involved, in order that population studies done farther south, in the breeding areas, may take this into account.

For those sea mammals that breed in the north—walrus, ringed seal (*Phoca hispida*), bearded seal (*Erignathus barbatus*), and some of the harbour seal population (*Phoca vitulina*), also the beluga or white whale and the narwhal, a program of research should include the following: (1) A census done by counting breeding colonies, summer schools, hunting kills, and by running counts from ships in transit, all of which must be kept up through the years. (2) The collection of reproductive tracts, stomach contents, and parasites, in sufficient numbers to give good material for laboratory study. (3) The collection of teeth and possibly certain bones (bacula, for instance) for ageing

purposes, so that the age composition of the population may be determined; and the discovery of good methods of ageing in general (the use of teeth is quite new for seal and walrus, and there may be other means). (4) The study of migrations, especially winter distribution. It is not known, for instance, whether the walrus of Hudson Bay remain within the Bay during the winter or not, nor is it known which group of walrus visits Akpatok Island in early July each year. Something of the winter distribution could be discovered by air surveys, but the only final way of establishing migration habits is by marking the animals at the breeding grounds. This presents quite a problem, especially in species as large and formidable as the walrus, or as elusive as the beluga, and one of the most important problems to be solved is just how to mark them.[1]

Systematic and zoogeographic studies

The fauna of the North American Arctic and Subarctic waters and coasts (except those of Greenland) is still poorly known. The large gaps in the distribution maps are being filled in, but even when the work of the *Calanus* and *Blue Dolphin* expeditions, and of the Point Barrow Laboratory, is published, there will still be a great deal of faunistic work to do, particularly in the Central Arctic section, and in the Beaufort Sea. The present signs are that when these groups are filled in, the results will be very interesting. Ekman (1953, p. 159) has collected evidence to show that "a considerable part of the North Atlantic boreal fauna and the Polar Sea arctic fauna is derived from the North Pacific", and although the evidence is of the equivocal sort that zoogeography is often forced to use for lack of anything better, it is also the sort that is accepted by most zoogeographers. The shelf fauna of the North Pacific contains many more species and genera than are to be found on the North Atlantic shelf, and it is only in the Pacific region that endemic families are found. Given certain premises (which are not quite argument-proof), this is evidence for the dispersal of the fauna from the Pacific to the Atlantic. However that may be, there is good indication that there has been a dispersal from the North Pacific or Bering Sea area eastward to the Canadian Eastern Arctic, and also westward to the waters of the Siberian shelf, which has hitherto left the coasts of Greenland and of northwest Europe almost untouched. This is at present represented by the land-locked seal of Seal Lakes in the Ungava Peninsula, by certain of the fishes in Hudson Bay and Ungava Bay, and by several amphipod species; and the full study of the Eastern Arctic fauna will no doubt bring many more such examples to light. Such distributions are doubtless a legacy from early postglacial times, and the whole study of arctic zoogeography has an important bearing on the glacial and postglacial history of the North American Arctic.

Within the arctic zone, the phenomenon of circumpolarity appears to be fairly common, although the addition of the North American sector to the

[1]Since this was written, walrus tags have been designed by both the Canadian Wildlife Service and the Fisheries Research Board of Canada, and have been used in northern Hudson Bay in the summer of 1954.

picture may well change our ideas in this as in other aspects of northern marine distribution. It may well be that there are variations within circumpolar species, which will be significant of isolation within the circumpolar area, especially in the littoral and benthonic species; and even for holoplanktonic forms there is the possibility of isolation by current systems. In the marine subarctic, the true monotypic circumpolar species is the exception rather than the rule, and the investigation of the extent and quality of variation within subarctic genera is a matter of great interest to the student of evolution, and will be much extended by the filling in of the North American gap in our knowledge.

As for the fauna of the deep basins, there can be little doubt that even in the regions where most exploration has been made, as in the Greenland and Norwegian seas, there is still much to be added. In Baffin Bay our present knowledge is based almost entirely on the results of one short expedition, the *Godthaab* expedition of 1928. At the present stage of the study there appears to be a large number of species common to all the arctic basins (Arctic Ocean, Norwegian and Greenland seas, and Baffin Bay), a fact which may have interesting implications concerning the recent history of those depths. Before any firm conclusions can be drawn, however, there is much deep-water dredging and bottom sampling to be done.

There are many groups, which cannot be mentioned in detail here, whose systematics are in a somewhat chaotic state. For some of these, such as the Gadid and Liparid fishes, we need embryological studies in order to untangle the pattern of relationship, and for others, such as several amphipod families, we need large collections from the whole circumpolar field.

Finally, since zoogeography is a study of a dynamic, not a static, phenomenon, and since changes in the distribution of marine animals can be of decisive economic importance, it is necessary to keep routine observations going every year, or at regular intervals, not only upon the fauna itself, but upon the hydrographic conditions which, more than anything else, determine the composition of the fauna. Changes in the marine climate have not been treated in this paper, partly because of lack of space, partly because their existence and their overwhelming importance are now well established, and the continued study of them may be taken for granted.

The author wishes to acknowledge his indebtedness to Dr. Gunnar Thorson of the University of Copenhagen for reading the manuscript of this paper, and for valuable suggestions.

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SOME BOTANICAL PROBLEMS OF THE ARCTIC AND SUBARCTIC REGIONS*

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THE arctic and subarctic problems dealt with in this paper are primarily botanical. However, they are of such a nature that they require delving into many other phases of natural science, particularly surface geology, meteorology, and human geography. Consequently such problems as are suggested will have repercussions in these fields as well as in the broad field of biology. Within the field of biology my personal experience has been primarily in the study of vegetation, so that the problems I suggest will, inevitably, be weighted in that direction.

The solution of many problems in boreal biogeography will yield valuable and practically useful information for many purposes, civilian and military. The significance of these problems in the extensive use of arctic and subarctic lands by human populations lies first in the evidence they can give of the major geographic patterns or natural areas in the boreal regions. It is upon these major patterns that the outlines of use must eventually be based. This is an old concept which has been used with varying degrees of intensity and precision during the opening of the Western Hemisphere to European occupation, and the idea is still a good one. Its application is no longer simple, however, and in the hands of modern, highly trained specialists it can be badly misused. In earlier times it was successfully applied by broadly trained naturalists such as Douglas, Richardson, Macoun, and many others. It depends for its successful use upon what might be called correlative thinking in the natural sciences, and this type of thinking has become rather rare in these days of extreme specialization.

A second system of application is a refinement of the first. It involves the use of the natural vegetation in its relationship to local environments to indicate the cultural capabilities of the land. A third application is of large military significance. It involves the use of vegetation as an indicator of the "kind of ground".

All of these applications of botanical science to the intelligent use of the land depend upon a knowledge of the vegetation in all its aspects. Such knowledge is still in its infancy for most of the arctic and subarctic regions.

It is possible to make a general subdivision of northern vegetational problems into two groups, though the division is not a natural one and is to be used only for convenience.

*Reprinted from *Arctic*, Vol. 6 (1953) pp. 68–74.

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Floristic problems

The basic floristic problem in boreal North America is the development of a comprehensive, descriptive flora, with keys and illustrations which will aid in the identification of plants. No such comprehensive flora now exists. The last one attempted was more than a century ago. At present we are dependent upon regional lists of species, and upon a great mass of miscellaneous papers embedded in periodical literature.

The Eastern Arctic is pretty well covered by Nicholas Polunin's 'Botany of the Canadian Eastern Arctic,' Parts I and II. These papers cover the region from northern Ellesmere south to the 60th parallel. They do not, however, cover the Western Arctic islands or go much beyond the western coast of Hudson Bay, and they do not include Greenland.

My own published work covers the central and southern portions of the Mackenzie drainage basin. In the western parts of boreal America the only comprehensive work is that of Eric Hultén on the flora of Alaska and Yukon. This has been published in parts, and is now complete. The final part of J. P. Anderson's 'Flora of Alaska and adjacent parts of Canada' was issued in April 1952. Of the above papers, only those of Hultén and Anderson contain keys for the identification of the plants. Erling Porsild of the National Museum of Canada has a manuscript flora of the Canadian Western Arctic, and has recently published a critical and comprehensive treatment of the vascular flora of southeastern Yukon adjacent to the Canol Road.

All of these papers are, of course, based upon such collections of plants as have been made to date. They cannot be regarded as complete in any sense, for there are vast areas in boreal America where botanical collections have never been made. Such fundamental field work is necessary in the Western Arctic islands and particularly in the interior portions of all the larger arctic islands. Our present knowledge of most of these islands is based upon collections made at relatively few points on their shores. The same is true of the interior of the Labrador-Ungava Peninsula and the interior of Keewatin. Even south of Keewatin there are large botanically unexplored areas in northern Manitoba and northern Saskatchewan. There are huge areas in western Mackenzie, northern Alberta, northern British Columbia, and Yukon that remain to be explored. The same is true, of course, in Alaska, particularly in the mountain and plateau regions away from the main routes of travel.

The development of plant ranges and patterns of distribution will remain uncertain and incomplete until this exploration is much further along than it is now. In planning and carrying out the work, it is essential that trained men should be engaged in it. The number of persons who have collected plants in boreal America during the past century and a half is legion, but it is safe to say that not more than a dozen of them have been able to do anything that would remotely resemble a comprehensive job. If the amount of money and time that has been spent in this pursuit over the years could have been concentrated in the hands of a few well trained people, the job would have been done long ago.

In order to be a good collector, a man has to know a great deal about plants and the way they differ from one another. This can only be got from training and experience. It has been a prevalent misconception, persisting for generations, that anyone given a plant press could collect the flora. Most of the money and resources that have been spent under this misconception have been wasted. We should set out systematically to cover the area, first on a regional basis. Then all the collected materials and information should be concentrated in one place, or at least in the hands of one man who would be competent to put it together in a usable form.

This project is placed first because it is necessary to produce the grist before the phytogeographic mill can be operated profitably.

The plants which occupy a given spot in boreal America are there because they were available when a place was opened to them, because they had the capacity to move into the place when it became available, because they had the capacity to adjust themselves to the physical and biotic limitations presented by the situation, and because they were able to reproduce themselves there. It is quite obvious that simple analyses of climate and soil will not explain the occurrence and behaviour of the plants that are found in a given place, and it is necessary that the identities and geographic origins of the plants be taken into consideration, as well as migrations and adjustments in time and space.

Vegetation is composed of individual species of plants, each of which has a population that varies widely in numbers from place to place, and in prominence and significance in the total plant cover. Each of these species has had a complex evolutionary history, and now contains genotypes that are the result of this history and of the various vicissitudes that the species has been going through during its history. Within its population these genotypes are commonly not evenly distributed, so that the behaviour of the species in one region will give no indication of its behaviour in another. In one area it may be predominant in numbers and in influence upon the total vegetation, and in another it may be reduced to insignificance. Herein lies a mass of problems in the nature of species—problems that are of fundamental significance to the study of vegetations and ultimately to their significance in the use of the land. Experimental studies in the genetics of boreal species, carried on in the field, are at the base of these problems.

This can be illustrated with the common white spruce, the most important timber tree in the subarctic forest. It is generally recognized as a single species ranging from Newfoundland to Alaska. It contains at least three separate entities which differ in general appearance, in local habitat selection, and probably in the quality of the wood. The most easterly form ranges westward into Saskatchewan, and probably into northern Alberta. It is a tree of moderately drained upland soils and flood plains. Another form ranges through northern British Columbia, northern Alberta, southern Mackenzie, south in the Rocky Mountains, and northwestward into Yukon and Alaska. It is the so-called "Alberta spruce", and has a much wider range of habitat selection than the eastern spruce. I have found it on high mountain slopes, on dry sand plains, and in muskegs. There is a great variety in the quality of its

wood, though, so far as I know, no one has ever made comprehensive tests of these qualities. A third phase of the white spruce grows in Yukon, western Mackenzie, and parts of Alaska. It has only recently been described, and its range and characteristics are only partially known. It appears to be quite limited in the range of its habitat selection, growing on gravelly terraces and glacio-lacustrine deposits. I have also found it on dry south-facing mountain slopes. I think I am safe in saying that nothing whatever is known about its timber qualities, or its genetic origin. Workers in western Alaska are turning up still another spruce, which may or may not be a separate strain.

These spruces are sufficiently well known to indicate a pattern of distribution, and we know that they differ superficially. Beyond this we have nearly everything to learn about them, except that we know the timber values of the eastern form and something of the values of the Alberta spruce. This kind of problem can be multiplied by the hundreds in the boreal flora. In detail it has all the aspects of a problem in pure science, but it can have immediate repercussions in the practical use of the northern lands. It will require for its solution not merely a working knowledge of taxonomy and genetics, but also of the whole gamut of geological and meteorological changes that have affected boreal North America during and since the Pleistocene. Corollaries to it are broad problems of speciation in all of the boreal parts of the world, such as the occurrences and distribution of endemism, polyploidy, apomixis, and the like. The broad outlines of some of these problems are beginning to take form, but we are only at the beginning.

It has been suggested above that the ultimately useful units in the flora may not be the units that will be recognized by the taxonomists who develop the "Flora", because of genetic variations within the species. In key situations, therefore, experimental studies in the nature of certain species should be initiated *in the field*. Some of these experiments will be comparatively long-term affairs, and will have to be established at bases that can be continued for some years. There are plenty of establishments throughout the boreal regions which could be used for such purposes, given funds for necessary adjustments or reorientations.

Men of special training in practical genetics will be necessary for this work. They should be men who are broadly trained in botanical science, rather than one-sided students of plant inheritance, for it will be necessary that they understand something of the broad significance of what they are doing. They must be content to spend long summer seasons at relatively isolated stations. It is only from such work that we will learn how the taxonomist's species have been put together during glacial and postglacial time.

The history of vegetation involves the study of plant fossils which, in the present problem, involves the study of peat. Very little is known of geologically recent peat deposits in the north. One of the reasons for this is that the peat is frozen and cannot be sampled as easily as that in temperate regions. The study of peat deposits in the north involves to a considerable extent an engineering problem. It is essential, however, that it be done if we are to understand the geographic patterns involved and to make them useful.

Problems in plant communities

A second great complex of problems relating to the plant cover is in the study of the masses of vegetation which are made up of the various species. In this field some of the main outlines of geographic distribution have been known for a long time. The boundaries between the tundra and the forest, whether on the northern interior plain of the continent or on the mountain slopes, are relatively well known. One of the great natural boundaries in the world's vegetation is between the northern forest and the tundra. At present, however, this boundary is little more than an observed fact, for we do not have a clear idea of why it occurs where it does. It is presumed to reflect a climatic boundary, but how the climate differs on either side of it, and how the difference affects the growth of trees is very little known.

A primary characteristic of vegetation in the mass is that it is extremely unstable. It undergoes changes which may be due to influences external to itself, such as alterations of climate and soil. It is also affected by the results of its own existence on a given area, because in itself it alters the soils and the microclimates. It is also subject to modification, especially in the arctic and subarctic regions, by the influx of species from other regions, and by the effects upon it of grazing and other animals. The resultant of all these changes, both internal and external, is the vegetation on the ground at any point in time. It follows that the significance of vegetation as an indicator of the kind of ground, or of the usability of the ground for agriculture or silviculture rests upon an understanding of the rate and kind of changes that are occurring. Here are some of the most important problems in the boreal biota, and here again we are only at the beginning of the necessary understanding. Here also are excellent examples of failure due to extreme specialization on the part of field workers. Far too many of the students who have undertaken to use the vegetation for its indicator values in the north have failed to take into consideration its quality of instability.

The difficulties in the use of natural vegetation in the north for its indicator values are manyfold greater than they are in temperate regions, because the very base for interpretation is a new and little understood one. In temperate regions the development of vegetation is very closely related to the development of land forms under the influence of subaerial erosion. The fundamental concept here is the "cycle of erosion" by running water. Land surfaces are uplifted by orographic movements, stream gradients are increased, water tables are lowered, erosion is stepped up, and new flood plain deposits are formed. Vegetation on the uplifted surfaces is altered or destroyed, and develops on new deposits. Other effects related to this occur on beaches subject to wave action, or on dry surfaces subject to wind action. On the aquatic side, ponds and lakes are physiographic features that are made or reduced by surface changes due to erosion. Out of these complexes we have developed what is known as the "physiographic ecology" of vegetation.

In the arctic and subarctic regions subaerial erosion is often a minor factor in the degradation of land surfaces, and the slow movement of surface materials

under the influence of frost is of primary significance. The effects of frost action on the details of surface configuration, and their significance in the moulding of larger surfaces, are just beginning to be known. Each year that geologists work in the Arctic they turn up new aspects of these processes. The development of vegetation there must be related to a developing knowledge of surface changes under the influence of frost. In short, a new brand of physiographic ecology must be written. Botanists are now making a fine beginning in this field.

It was said above that the indicator values in northern vegetation cannot be interpreted from simple observations at given points in space and time, because the vegetation is not a dead blanket, but rather it is an unstable, developing, biotic phenomenon. The whole plant cover of the boreal regions must be studied and interpreted in this light if it is to be significant for purposes other than immediate utilization. Attached to many kinds of parties engaged in field operations, whether they be in photo-interpretation, geological investigations, engineering reconnaissance, or agricultural and forestry reconnaissance, there should be men who are especially trained to interpret vegetational change. These men, again, should not be too highly specialized, for they must have a working knowledge of floristic geographic phenomena, and they must understand the relationships between vegetation and climate and soil. They must have a working knowledge of the evolution of soils and land forms, and of the occurrence and significance of microclimates and of climatic change. Of all the men in the field, these will be the most difficult to find, for our system of training students of vegetation during the past fifty years has not produced many of the kind that is necessary. On the other hand, the study of vegetational change involves many disciplines which can be applied by specialists provided there is adequate direction and correlation.

Arctic vegetation bristles with problems relating to the physiological relations between the plants and their environments. Water relations in arctic vegetation are very poorly understood, as are those involving the availability and use of mineral salts. The nitrogen cycle in arctic and subarctic regions is particularly worthy of investigation. However, I do not believe that these physiological problems should be stressed until much more basic work on the geography of the plant life has been done. A certain amount can be accomplished by men who are versed in the intricacies of such problems and who can be attached to field parties, but far too much physiological work has been done without reference to the basic facts of the identity and natural occurrence of plants. This work now stands alone and probably can never be fitted into a natural context of vegetation. Physiological research on arctic plants must somehow be carried into the field, out of the laboratory. The progress that has been made by the group working at Point Barrow is encouraging.

The use of lands for agriculture, grazing, or timber production in the American north is in its early stages. My own studies indicate that frost and the short growing season in most parts of the Arctic and Subarctic are not so significant in this connection as is the shortage of water. Whoever

attempts to develop northern land should approach the problem with a completely open mind, trying many kinds of plants, in many kinds of sites, and by many modifications of the existing growing conditions.

The following is an outline of problems derived from the above discussion:

Botanical exploration

1. Floristic exploration:
   Western Arctic islands
   Interior of arctic islands
   Interior of Labrador-Ungava Peninsula
   Interior of Keewatin
   Northern Manitoba and Saskatchewan
   Western Mackenzie
   Eastern and northern Yukon
   Northern British Columbia
   Mountains and plateaus in interior Alaska.
2. Description and analysis of plant communities:
   Needs to be done in most of the boreal regions.

Flora of boreal America

3. Preparation of a comprehensive "Flora", with keys and descriptions, preferably illustrated.

Origin and distribution of the flora

4. Preparation of range maps of species.
5. Investigation of genetic variability in species as related to their geographic behaviour in Pleistocene and post-Pleistocene time.
6. Relation of species distribution to development of landscapes.

Origin and distribution of plant communities

7. Relation of development of plant communities to development of arctic and subarctic land forms, particularly with respect to cryoplanation.
8. Reconstruction of post-Pleistocene landscapes, both as to morphology and biota.
9. Investigation of the concepts of "succession" and "climax" as applied to boreal vegetation.
10. Relation of climates, both local and general, to the nature and distribution of vegetation.
11. Effects of man and other animals upon the vegetation.
12. Effects of fire upon native vegetation.
13. Studies of peat deposits and other fossil remains.

Problems in applied botany

14. Sustained yield utilization of native forests and grasslands.
15. Investigation of agricultural expansion.
16. Interpretation of vegetation as an indication of "kind of ground".
17. Interpretation of air photographs for the mapping of natural resources and "kind of ground".

SOIL RESOURCES AND AGRICULTURAL DEVELOPMENT IN ALASKA*

Allan H. Mick[1] and Hugh A. Johnson[2]

BEFORE the Second World War there was little need for commercial agriculture in Alaska. Most people were living in coastal areas where they could be supplied more economically by water routes from the south. Major potential farming areas, all located in the interior, were far removed from the consuming population. Construction of the Alaska Railroad earlier had stimulated demands for vegetables and potatoes, which were met by a few growers who had drifted to subsistence farming following a gradual collapse of mining as the principal industry in the interior. By the early 1930's these local markets had so deteriorated that plans for colonizing the Matanuska Valley provided only 40-acre and 80-acre part-time subsistence farms, with occupants procuring a major portion of their income from off-farm work.

Although commercial agriculture is new in Alaska, early Russian fur traders raised vegetables in small gardens and imported a few cattle to eke out food supplies between the uncertain visits of their company ships. In the interior, gardens followed the miners and, where horses were brought in to transport freight, a few native grasslands were mowed for hay and later plowed to grow oats and potatoes. Timber was cut for fuel or building materials, and small-scale land clearing followed more or less accidentally.

By 1898 there was sufficient interest in Alaska's agricultural potential to warrant the U.S. Department of Agriculture opening an experimental station at Sitka. In the next two decades six more experimental farms were established. Of these, the Rampart Station in the Yukon Valley was the northernmost; the others were at Fairbanks, Copper Center, Matanuska, Kenai, and Kodiak. All were designed to test crop varieties in subarctic environments. Livestock breeds were introduced at Fairbanks, Matanuska, and Kodiak, the Kodiak farm being closed after the Katmai eruption in 1912 covered the island with ashes, destroying any possibility of growing forage for several years.

Federal interest in these projects languished after they had demonstrated that farming was feasible in what had before been generally regarded as a forbidding land of ice and snow. By mid-1932 only the Fairbanks and Matanuska experimental farms remained, and their operation had been taken over by the University of Alaska. At that time and for several years to come,

*Contribution from the Alaska Agricultural Experiment Station, Palmer, Alaska. Paper 2, Journal Series.

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Photo: Alaska Agri. Expt. Sta.

Fig. 1. Vegetable farm on Subarctic Brown Forest soil near Fairbanks. High income vegetable crops are grown for both civilian and military markets. Potatoes, celery, chard, cauliflower, lettuce, cabbage, broccoli, carrots, radishes, and turnips thrive under good management practices.

the Territory lacked an adequate tax structure to support a land-grant college program comparable to those of many states. Little money was budgeted for agricultural research or for extending technical knowledge to the few farm families in the Territory. Pioneer farmers depended chiefly on management practices with which they were familiar, augmented by whatever information a small college staff could gather concerning suitable varieties and practices.

Present scope of commercial agriculture

The federally sponsored Matanuska Valley colonization was tremendously important in laying the groundwork for commercial agriculture and farm development. In addition to carving fields from the wilderness—a struggle so frustrating that few individuals ever see their places reach full production—this project created a rural community sufficiently large to support its own service and marketing agencies. A small nucleus of subsistence farms was thus fairly well established before the war. During the war years the demand for local food production fostered commercial farming within this framework. Continued postwar growth of defence establishments has created large stable markets which enabled the community to survive and even expand in the face of great incentives offered by other trades. In the past few years commercial agriculture has grown rapidly and gained in economic importance.

By 1950 there were 878 rural families homesteading, developing farms, and engaged in commercial production in the Territory, but less than half

Photo: Alaska Agri. Expt. Sta.

Fig. 2. Certified potato seed is grown on this farm near Homer, Kenai Peninsula. Soils are fertile and inherently productive, but moderate summer temperatures do not favour grain production. Although well suited to grassland farming, this country lacks an adequate fresh milk market.

depended on farming for their major source of income. Some 300 full-time and part-time farms are now operating in the Matanuska Valley, marketing their crops in Anchorage and nearby military bases; another 35 part-time farms and a dozen or so full-time farms are located in the immediate neighbourhood of Anchorage, while scattered between Kenai and Homer are 40 to 50 partially developed farms, which are expected shortly to send more foodstuffs into Anchorage now that the new highway connections have been completed. A new military market is also emerging near Kenai which should stimulate farming in nearby areas. Another scattered community of about 60 farms is located near Fairbanks. Dairying and grain production are of importance to some farms, while the rest grow vegetables and potatoes for military establishments.

The total farm income in Alaska from sales of foodstuffs amounted to $2,819,836 in 1953. Of this total, fresh milk sales accounted for 38.1 per cent, vegetable and potato sales for 43.4 per cent, livestock products other than milk for 5.3 per cent, and dressed poultry and egg sales for 13.2 per cent. Fur and wool sales were valued at $180,000. The value of foodstuffs sold was roughly divided as follows: Matanuska Valley, 56 per cent, Tanana Valley, 16 per cent, southeastern Alaska, 11 per cent, Kenai Peninsula, 6 per cent, Anchorage area, 8 per cent, and Kodiak, Chirikof, and the Aleutian islands, 3 per cent.

In all of Alaska an estimated 13,000 acres were cropped in 1952 while some 3,000 to 5,000 acres of cropland remained idle. Grazing leases covering

Photo: Alaska Agri. Expt. Sta.

Fig. 3. An oat–pea field in the Matanuska Valley (Knik soil series). Forage from this field was used to compare field curing on stakes with mow drying. Similar research has shown that ensiling is the most practical method of preserving forage in Alaska.

518,00 acres were scattered from Kodiak to Unalaska and Umnak islands in the Aleutian Chain. Grazing rights were also leased on 39,000 acres in the Matanuska–Susitna region. A more accelerated expansion of farming is hindered by high land-clearing costs, an acute lack of venture capital, land speculation, and scarcity of labour. Moreover, present policies are ill-adapted to placing public lands in private ownership under Alaskan conditions, and this combined with a lack of suitable credit discourages rapid settlement by farmers in areas suitable to agriculture. While development of power, improved transportation, and increasing population contribute to ever greater demands for local farm products, incentives to develop new farms are not yet great enough to compete seriously with the high incomes offered by construction and service trades.

On the other hand, efficient dairy farms provide fairly stable employment throughout the year and yield a good living. In 1953, for example, average annual net returns from 38 leading dairy farms amounted to $4,850. The average net returns on potato farms is about $3,500, and on poultry farms about $3,000 a year. Dairying, which is well-adapted to Alaska's natural and economic environment, represents the most stable farm enterprise. Potato and vegetable growing is usually the beginning phase in establishing a farm, though a few specialized potato and vegetable farms are being developed. Further growth is toward dairy enterprises representing a climax type of farming in the Matanuska and Tanana valleys, and today, particularly, to a general type of farming based on poultry, meat, and eggs.

Soil resources

Soil development and morphology can supply some clues to a knowledge of the environments of Alaska's farming areas. Mature soils—those that result from the full force of climatic and vegetative soil-forming factors—include only the Tundra and Podzol great soil groups. Podzols are usually found in well-drained sandy surface mantles. Where very fine sands and silts have accumulated, podzolization is feeble and transitional to the intra-zonal Subarctic Brown Forest soils.

Subarctic Brown Forest soils

Most crop production occurs not on Podzols but on the related well-drained Subarctic Brown Forest soils. Geologically, these soils have weathered for only a short period; hence they have high potash levels but are deficient in organic matter and nitrogen. Available phosphates are usually in short supply. Under cultivation surface layers dry out extremely fast, but, for the most part, these soils respond well to good management practices.

The upland loess mantles near Fairbanks are typical of Subarctic Brown Forest soils, which support a boreal forest. Under a thick peaty carpet a thin acid mineral horizon is stained by intermixed organic matter. At 3 inches or so in depth there occurs a gradual transition to an underlying yellowish-brown, vesicular, leached horizon. At 18 to 24 inches parent material usually is encountered. In the Tanana Valley this is a pale yellow, very fine sandy loam. Tanana Valley soils have developed in deep deposits of wind- and water-transported materials; they contain a lot of mica which is easily transported and are, therefore, subject to severe sheet and gully erosion, especially on the long steep slopes characteristic of the rolling hills near Fairbanks.

In the Matanuska Valley the best farmland consists of well-drained soils in an arrested state of development because their surfaces are continually receiving fresh additions of minerals from the broad beds of the Matanuska and Knik rivers. Both streams distribute a heavy load of glacial rock flour over their channel bars. Dust particles are picked up from there and carried generally westward over adjacent valley plains by strong local winds.

Knik and Bodenburg are the dominant series of the Matanuska Valley Subarctic Brown Forest soils. Both are characterized by banding derived from buried surfaces, by weak stratification, by particle size distributions of a youthful nature, and by wide carbon–nitrogen ratios. Cultivated fields are brown and billowy in topography. Subsoils are drab and mottled by poor drainage. Pore-size distributions are remarkably well-adapted to retaining large quantities of water. Under a climax forest, thick insulating organic mats encourage seasonal frosts to persist until midsummer; this persistent frost further impedes internal drainage. When cleared and cultivated frost layers disappear, internal drainage develops and these upland soils warm rapidly.

Surface layers of the Subarctic Brown Forest soils are usually acid. Subsoils are well supplied with calcium and magnesium although free carbonates generally are absent. Potash is usually present in adequate quantities for most crops. When cultivated, fields gradually become more alkaline, a process

associated with organic matter oxidation and a narrowing of carbon–nitrogen ratios. Fields known to be acid when first tilled 20 years ago are now neutral or slightly alkaline. The alkaline reaction of their fields is of immediate concern to many farmers who find their potato crops increasingly afflicted with scab. Sulphur treatments have not proved of value in correcting this soil condition.

Tundra and wet soils

The Tundra is the most widely distributed zonal great soil group in Alaska. In these soils a variety of vegetal cover subsists at very low levels of activity. Estimates for the recovery of lichens range from 3 years after moderate grazing to as much as 20 or 30 years after severe over-grazing. But even though plant growth is slow, decomposition of organic materials by micro-organisms is still slower. The net result is a thick accumulation of tough, fibrous, peaty material bound together with woody roots, stems, and rhizomes, sluggishly persisting year after year. This carpet is resilient and difficult to traverse except when frozen and covered with snow. In summer it remains saturated. The high insulating properties of this surface layer prevent summer warmth from penetrating mineral substrata which remain frozen for long periods. Most Tundra areas are underlain by permafrost at shallow depths. Small gardens thrive surprisingly well at favoured sites where the surface layer thaws out deeply enough each year.

Low drainage positions are occupied in limited areas by Ground-Water Podzols and over extensive areas by Half Bog soils. Both support rather sparse stands of scrubby black and white spruce. Bog soils locally called "muskeg" are found in undrained depressions and in places underlain by impermeable permafrost, rock, or clay. Some attempts have been made to cultivate wet soils included in farm holdings, but the great hazard of local frost has discouraged any widescale use. At present it seems unwise to encourage extensive drainage because of possible adverse effects on ground-water supplies.

At higher altitudes the intra-zonal Alpine Meadow, Mountain Tundra, and Mountain Half Bog soils are found, and the land appears to have little potential agricultural value except possibly for extensive reindeer grazing or for cattle range where associated with other sites capable of producing winter feed.

Fertilizer requirements

Farm management practices must include sound conservation principles to preserve the relatively thin surface soils and low organic supplies and to maintain adequate amounts of soil moisture. In addition most soils require generous applications of commercial fertilizers, especially nitrogen and phosphates, even from the very beginning, a fact that sometimes discourages the homesteader. Cultivation stimulates oxidation of soil organic matter and this process competes with crop plants for the little nitrogen inherently available. Nitrogen deficits can be made up by generous applications of nitrogen fertilizers only.

All fertilizers must be imported, and therefore their cost is high. Ammonium nitrate imports are complicated by a Coast Guard regulation made necessary by the fire hazard in shipping, but at $7.70 a hundredweight, it is still the cheapest and most efficient source of nitrogen available to Alaskan farmers.

With proper fertilization forage crops can be grown in abundance. This is one of several reasons why dairying is a logical enterprise. Crop production in Alaska is largely limited to cool-season species. Since the reorganization of the Alaska Agricultural Experiment Station in 1948, field crop research has concentrated on developing and selecting superior varieties of forage and cereal crops and on devising profitable means of producing those crops. The success of Alaska's livestock industry will depend in part on the extent to which these objectives are achieved and put into practice.

Effect of permafrost

North of the coastal mountain ranges agricultural land use is complicated by the presence of frozen subsoil even in sites where local summer air temperatures are suitable for growing commercial crops. While some permafrost phenomena are inherited from previous climates, others are more closely related to surface aspect and to the development of a climax vegetative cover with its associated insulating surface mat.

Many sites that otherwise appear arable may actually be underlain by ice lenses and blocks. In a few places near Fairbanks clearing and cultivation have apparently improved surface-heat absorption and sub-surface conduction, thus causing underground ice masses to melt. Unequal subsidence of the land surface has made a few acres unfit for further tillage. In other places large sinkholes have appeared. Plans for settlement in the Dunbar area west of Fairbanks were abandoned several years ago because the best surface soils appeared susceptible to this kind of deterioration.

Perhaps of greater significance is the fact that permafrost layers impede vertical drainage. Great expanses of level land remain wet throughout the summer and artificial drainage would require a vast reclamation project. East of Fairbanks a few favourably located sites have been stripped free of their forest and insulating mats, and the permafrost layers appear to be retreating, although vertical drainage has not yet become fully operative.

Another way in which permafrost inhibits the agricultural use of otherwise favourable sites is by interfering with domestic water supplies. In the Tanana Valley only a few satisfactory wells have been drilled in the upland area. Deep wells are both expensive and subject to freezing. Shallow wells are generally unsatisfactory because of limited ground-water supplies and sanitation problems.

Agricultural potential

Evidence of the kind of agricultural industry that can evolve in Alaska is available from similar natural environments in other parts of the world. In these areas, Tundra soils are generally considered non-agricultural and have

supported only primitive agricultural societies. Where Podzols are dominant settlements are usually small and have developed as a result of lumbering or mining operations. A subsistence agricultural economy, based on hay, potatoes, and root crops with limited grain production can be supported. Oats are initially grown for horse feed, and later for dairy feed as markets appear for livestock products. Because the climate favours growing forage, dairying has usually emerged as the main agricultural industry. Butter and cheese are important exports, though this is unlikely to occur in Alaska. Supplementary foods and fibres from other climates have to be imported, particularly if industrial growth occurs.

Recent studies indicate that agricultural development in Alaska will conform in part to these historical patterns. Alaska cannot be expected to produce all the food required within the Territory. The population is conditioned to an abundant and varied diet: fats, oils, sugar, legumes, grain products, fruits, and nuts are all staple items, and very few of these can be grown efficiently under subarctic conditions. Fortunately, national trends are toward increased consumption of meat, poultry, eggs, dairy products, and processed vegetables, many of which can be produced locally. Consumption of potatoes, while showing a downward trend in the United States, still greatly exceeds production in Alaska.

Viewed in the historical perspective of the westward population expansion across the United States, Alaska's present status is something of a paradox. A major part of North America was settled by farmers migrating from within, and extending an agricultural economy. During this period, which gave rise to the land laws and a unique land-grant educational system, farming was both the vocation and dominant way of life for most people. Land policies guiding the western migration were based on deliberate attempts to transfer public lands to private ownership. This device succeeded in broadening the revenue base supporting local governments and public services.

Many factors adversely influencing Alaska's agricultural growth are rooted in social changes occurring in the United States during the past half-century. Conspicuous among these changes is a decrease in the proportion of people on farms. Equally conspicuous is the high level of living won by those families remaining on farms. High farm living standards have always been basic to the national policy but a clear enunciation has emerged only in the last two decades.

Alaska's homesteading population reflects these changes in social structure and thinking. For example, homesteaders who grew up on farms or who had farming experience before coming to the Territory are definitely a minority. Most new settlers came from urban backgrounds where they were conditioned to highly organized public services and facilities. Many arrived and continue to arrive without adequate financial resources. On their homesteads they find that living standards to which they have been accustomed require large cash incomes that can be obtained during early developmental stages through off-farm labour only. Mechanization of farm operations and modern farm plants require additional cash outlays far in excess of what their

grandfathers found necessary in opening the 'west'. Beginning farmers are thus forced into off-farm employment to supplement their part-time farming enterprises in which risks are relatively high. Opportunities for off-farm work have been good, wages are attractive, and working conditions are more satisfactory to the former city dweller than those found in clearing and breaking land. Basic incentives in Alaska therefore tend to pull people away from the land. Antiquated land laws do not offer sufficient counter-incentives to reverse this trend. Historical pressures toward private land ownership are not effective in encouraging farming in modern Alaska.

Even the fairly well established farms are in a state of flux. Among fewer than 100 full-time farmers in the Matanuska Valley there were 25 farm transfers during the years 1951–3. Half of these departing families "were not adapted" in the minds of two long-time residents. Others left because of advancing age or poor health. This large turnover of commercial farms hinders the development of long-term farm management practices and the emergence of a sound food-producing economy.

An encouraging tendency is noted in recent Territorial legislation, which provides an appropriation for farm development and crop loans. Though the fund of $200,000 is small it has assisted in reducing a part of the risk now burdening Alaska's farmers. This legislation was an effective expression of faith in Alaska's future. It has served to reassure sources of private credit and entrepreneurs primarily interested in farming, small business, and processing industries.

Food potential

An index of Alaska's food producing potential is given in a recent figure which shows that 0.3 to 0.4 acre of good land per person is required to produce those food items that can be grown in the Territory at the present time, exclusive of beef and mutton. In contrast total land requirements for average national diets vary between 2.1 to 2.4 acres per person. Alaska therefore can be expected to provide only 12 to 20 per cent of the over-all acreage requirements of the population. Translated into terms of bulk, the products from this acreage might comprise from 30 to 40 per cent of total foodstuffs consumed in a well-balanced economy.

Present cleared acreages in the Railbelt are sufficient to supply a population of some 44,000 with that portion of their food requirements that can be grown locally. However, the permanent civilian population of this area is now estimated at 100,000, and during the summer the permanent population is supplemented by at least 20,000 transients, either touring or employed in construction trades. In addition four large military defence establishments swell local food demands. Doubling the present cropland areas still would not bring supply into line with demand. Present cropland areas could probably be tripled with little danger of over-supply, provided that most of the additional land is used for milk or meat production.

Despite great demands, which are reflected in high food prices, farm development is slow. During the past five years some 600 to 700 acres only

were cleared annually in the Railbelt. In the Matanuska Valley land-clearing lags even on established farms with considerable acreage available within their holdings. Dairy farms need from 25 to 30 per cent more cropland in order to operate most efficiently.

What justifies continued emphasis on developing Alaska's agriculture? Although the climate is subarctic throughout most of the Territory, there are several large areas of fairly good soils where local climates favour cool-season crops and forage. Experience has proved that cereals will mature and even tomatoes will ripen in the short summers of the Yukon Valley. Farther south, near Fairbanks, the frost-free period is long enough for cereals and forage, although summer temperatures are generally too low for warm-season vegetables such as beans and tomatoes. The coastal climate of the Kenai Peninsula is marked by longer frost-free seasons but also by lower summer temperatures which prevent cereals from ripening except in favourable years. Forage thrives in this environment which is well-adapted to dairying based on high protein silage feeds, and cool-season vegetables and potatoes also grow well.

Estimates of arable acreages in Alaska vary widely. Many figures have been derived from assumptions that all potential areas are equally accessible and that marketing opportunities are similar. Some estimates have assumed full exploitation of grazing lands remote from sites capable of producing winter feed. Assuming only an expansion of present social and economic patterns, and stipulating that most farmland will be used to produce those crops considered in the *per capita* acreage index mentioned above, the total area of potentially good cropland in Alaska probably amounts to about one million acres. Full utilization of this potential will supply part of the food requirements (exclusive of meat) for perhaps two and a half million people. Again assuming that future growth proceeds according to present patterns, this area might support 9,000 to 10,000 farms sending marketable surpluses to trade channels. If part of this cropland is diverted to meat production, *per capita* acreage requirements for food grown in Alaska might approach 0.8 acre; full use of Alaska's cropland along these lines would support some 5,000 to 6,000 farms growing some 60 per cent of the food requirements for a population of perhaps one million.

In addition there are perhaps half a million acres of poorer land associated with this good cropland. Small areas are now grazed; other areas in individual holdings may be included in farm management systems to supplement income from good land; and still others may lend themselves for extensive cropping practices like summer grazing or pulp growing. Only a small fraction of this poor land alone will support farms. Good use can be obtained only in conjunction with better areas in a well coordinated management program.

There is also an estimated 4 million to 6 million acres of summer grazing land. As mentioned, some coastal areas of this kind of land are already under lease. Other areas, notably in the interior where winters are severe, may never be used in the forseeable future because winter feeding and shelter require excessive capital outlays under the present economy. Where near farms that can provide shelter and winter feed, small areas are currently being

used for summer grazing. For example, a small valley in the Talkeetna Mountains, which bound the Matanuska Valley on the north, was used as summer range for dairy cattle during 1954.

Several million acres of grasslands also exist on Kodiak and other islands to the westward. Experience to date has indicated that livestock, such as cattle and sheep, can live and flourish on these islands on a year-round basis. Transportation, marketing, and other problems have been limiting factors.

When critical land needs develop in the North American continent it is possible that considerably more than a million acres may be farmed in Alaska. It is unlikely that full use of Alaska's agricultural land will occur until after other more southerly agricultural areas are fully exploited.

It is anticipated that the bulk of Alaska's consuming population will be located in the mainland, since experience has proved that southeastern coastal settlements cannot be supplied efficiently against competition from the south. With favourable shipping costs there is a definite possibility of exporting food from Alaska to Japan and other over-populated Oriental areas, but it will require high production efficiency. Shipping may be tied in with wood export, a development that appears to be nearing realization.

As already implied, agriculture will grow only to supplement other interior industries which must provide a means of livelihood for the great mass of consumers. The current construction phases of the defence program may provide sufficient impetus to bring an additional 200 to 250 farms into full production, but it is unlikely to require more. Exploitation of Alaska's power resources including water, coal, and petroleum will create additional population pressures and support a larger number of producing farms.

Agricultural research

Following direct congressional action, agricultural research in Alaska was reorganized and intensified in 1947. Since then Territorial and federal appropriations annually have made available some $400,000 to $500,000 for this purpose. Research is now conducted jointly by the U.S. Department of Agriculture and the University of Alaska. Major efforts have concentrated on strengthening the dairy industry by increasing local feed supplies through better management practices and better crop varieties, by promoting farm efficiency, and by improving dairy herds through crossbreeding and introducing superior germ plasm. This program has already stepped up dairy efficiency: in the Matanuska Valley average milk production per cow in 1951 was 8,900 pounds as compared with 7,200 pounds in 1947.

Other major research investigations have been made on fertilizer and soil management practices, on bromegrass nutrition, on searching for adapted cereal and forage varieties, on breeding, cultivating, and storing of potatoes, and on analysing markets and agricultural potentials. Supplementary projects have explored the use of native lumber resources for farm structures, have improved insect and weed control measures, and have shown the necessity for plant disease control on farms. Plans for the next biennium are limited largely

to basic problems already under consideration. As additional funds become available, they will be used to enlarge the attack on the most basic and neglected field—that of animal nutrition in subarctic regions. Primary objectives are to determine the nutritional value of Alaska-grown foodstuffs, and to assess modern diets in Alaska.

To strengthen the current agricultural research program, which is chiefly concerned with production research, the following subjects require further study:

1. *Winter survival mechanisms of plants:* Extension of commercial agriculture into the Subarctic has given several clues concerning winter survival mechanisms of plants. Because most commercial crop plants were evolved in more southerly latitudes their conditioning mechanisms apparently fail to respond to controlling factors in a subarctic environment. This response failure is now being associated with photoperiodism. Changes in light quality and intensity may play a larger role in physiological preparation for winter than has generally been thought. If winter-hardiness factors can be isolated and studied in detail, this knowledge will benefit all production areas.

2. *The importance of moisture deficiency as a limiting factor in arctic and subarctic food production:* As production management practices intensify, efforts must be made to minimize the limiting features of seasonal moisture distribution and of absolute moisture deficits. The following questions should be studied: Can present irrigation systems and techniques be used in Alaska? What are the power requirements? How much water is needed? Will soil moisture retaining capacities limit the use of water? Will water temperatures limit plant response? What are the cost factors? What are the magnitude of crop responses and where is the point of limiting returns?

3. *Reindeer:* Large areas of arctic and subarctic land masses are adapted to extensive grazing. Reindeer can reproduce and grow in this environment. But what is the carrying capacity of the range? Is the range susceptible to improved management practices? How intensively can the range be used? Will reindeer respond to improved feeding and breeding practices? What is the nature and size of the reindeer market? What economic factors are limiting? What social factors? Is this a possible food crop that merits development?

In addition to these major production problems there are problems of living conditions, of marketing, and of utilization both of land and of food crops. Some of these are very closely related to production, because the answers will determine to a large extent whether or not additional farm development takes place. Unless farming in the Subarctic offers suitable incentives in terms of good family living, it will not be able to compete for labour and capital. The solutions of the following problems are needed:

1. To reduce high labour costs, specialized equipment must be designed and tested in spite of the present small market volume.

2. Adequate and inexpensive housing for man and animals must be designed, and storage facilities must be adapted to the subarctic and arctic environments.

3. Cheaper methods of clearing and preparing land must be found. Some method must also be devised of financing developing farms. As long as the original entryman must carry the entire burden, farm expansion will be slow.

4. Finally, new markets, new products, and new processing methods must be developed if Alaska's agriculture is to become financially and numerically significant.

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SOIL AND AGRICULTURAL PROBLEMS IN SUBARCTIC AND ARCTIC CANADA

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RESEARCH on soils and agriculture in the Canadian north has so far been confined almost entirely to government work in the subarctic regions of the northwest.

Soil investigations, although only preliminary, have been sufficient to provide useful information on the nature and development of soils in the Subarctic. During the past eleven years the morphology of the soils, the approximate distribution of the different types, and their possible use for agriculture have been studied on traverses along the Alaska, Haines, Whitehorse–Mayo, and Mackenzie highways and along the Yukon River as far north as Dawson, and the lower Liard, Slave, and Mackenzie rivers. The observations made on these trips and the chemical analyses of the samples collected from representative soils have been published by Leahey (1943, 1944, 1947, 1953, 1954 a,b).

Our knowledge of the soils of the arctic and eastern subarctic regions is meagre. Apart from an investigation in the Chimo district of Ungava Bay in the summer of 1954, the only direct information has come from the observations made and samples brought back by travellers whose primary interest was not in the soils. Special mention should be made of the useful paper by Feustel, Dutilly and Anderson (1939), which records the analyses of a number of samples collected by Dutilly.

At present the Department of Agriculture maintains two small experimental substations north of 60°N., one in the Yukon and one in the Mackenzie Valley. The Yukon station, which is located along the Alaska Highway at Mile 1019, about one hundred miles west of Whitehorse, was established in the fall of 1944 on a virgin site, and experimental work was started in 1946. The Mackenzie Valley station, at Fort Simpson, was established in 1946 on cultivated land, and experimental work could therefore be started the following year.

Although systematic experimental studies on agriculture in the Yukon and the Mackenzie Valley really commenced with the work of these stations, some valuable information had previously been obtained from cooperative tests with local residents. These tests, first started in 1917, were however only intermittent, and for the most part lacked direct technical supervision. Hence it was difficult to estimate the value of the results.

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The technical staff at each of the stations consists of a resident officer in charge, and two or three students from agricultural colleges during the open season. The first progress reports of these stations (Abbott, 1954; Gilbey, 1954) have now been published and show that experimental work has concentrated on field testing of the comparative adaptability of different field and horticultural crops, of winter hardiness of biennial and perennial crops, and of methods of crop production. Studies on livestock, including poultry, have been limited to observations on feeding and winter care. In addition to these investigations at the stations, some cooperative tests have been continued with local residents.

These experimental stations are reasonably well located for studying agricultural problems in areas without permafrost in the southern Subarctic. Probably some of the findings, especially those concerning kinds and varieties of crops, will also apply to the northern Subarctic. These stations, however, were not primarily established to carry out experimental work in the Subarctic, but rather to study agricultural problems in those specific parts of the Yukon and the Northwest Territories where commercial agriculture appeared most feasible.

Many other problems of northern agriculture, particularly the breeding, selection, and development of hardy varieties of cereal, forage, and horticultural crops, and studies on the control of biting flies are being investigated by scientists of the Department of Agriculture both elsewhere in the north and in the south.

Future research needed

Before our knowledge of the soils and agricultural possibilities of the north can be considered adequate, much research will have to be done on the nature of the soils, on the effect of the soil-climatic environment on agriculture, and on factors governing the success of different types of agriculture under various environmental conditions. We cannot at present appreciate all the problems which must exist, but the lines of investigation mentioned below appear to be of major importance.

Soils

Exploratory soil surveys: Information on the nature of the soils is required from most northern areas, and could be obtained by widely spaced traverses or by spot examinations in selected areas. Studies on the morphology of soils in widespread areas, coupled with chemical and physical analyses of representative soils, would provide basic information for the classification of arctic and subarctic soils, as well as on their development, and on their possible use by man. Furthermore, such examinations would serve as controls for information taken from air photographs and from geological and botanical sources. In this way general soil maps of northern Canada could be prepared.

Systematic soil surveys: The systematic mapping, description, and classification of soil types in selected areas would provide valuable type sections of the soils in the various physiographic and climatic regions. Such surveys are

Fig. 1. Buildings on the Yukon Experimental Substation at Mile 1019 on the Alaska Highway. The buildings are scattered as a fire protection measure.

Fig. 2. Plot field for cereals at the Yukon Experimental Substation.

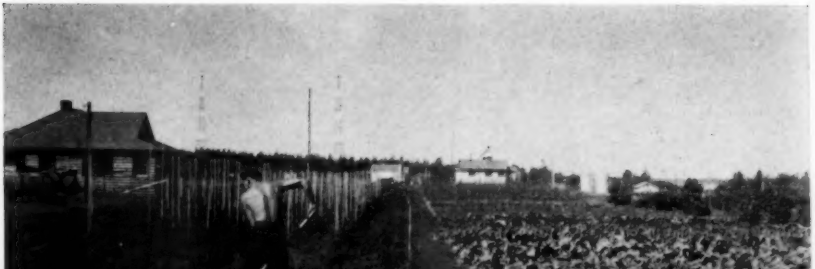

Fig. 3. Vegetable testing field at the Fort Simpson Experimental Substation, Northwest Territories.

particularly important for areas which are known to have agricultural possibilities, since they would show the extent and nature of the land suitable for agricultural development, and would provide basic information on proper land use.

Permafrost: The effect of permanently frozen subsoils on soil development, crop production, and soil management is not well understood. Information is needed on the effect of permafrost on soil temperatures, moisture relationships in soils, recession of permafrost under different climatic conditions when land is cultivated, and means of controlling the level of permafrost. The conditions under which ice blocks occur in soils requires investigation since pitting causes serious damage to some soils when the land is cleared and the ice melts. The effects of permafrost on the construction of roads, fences, and buildings must also be studied.

Micro-organisms: Very little information exists on the kinds, number, and activity of micro-organisms in the soils of northern Canada. In addition to such studies information is needed on the decomposition of organic matter, nitrification, the activity of nitrogen-fixing bacteria, and methods of promoting a desirable microflora in cultivated northern soils.

Soil formation: Very little is known on the processes of soil development in the arctic and subarctic regions. Among the investigations needed to provide information on this matter are studies of the nature and extent of the weathering of minerals in the mineral soils, the effect of permafrost on soil disturbance and on temperature and moisture relationships, the comparative effects of forest and tundra on soil development, and the accumulation or loss of organic matter in the mineral horizons. In connection with the organic soils, investigations are needed on their relative rate of formation under

different climatic environments, the decomposition of peat, and the nitrogen-fixing properties of the plants, the remains of which form organic soils.

Soil fertility: The chemical, physical, and biological environments which these northern soils provide for the growth of native and cultivated crops are not well understood. Some of the desirable investigations mentioned elsewhere in this paper will provide information on the factors affecting the fertility of the soils, but direct investigations, particularly where the soil environment can be changed, would be even more useful. Although the nature of such investigations would be governed by the particular problem under consideration, in general they might well include studies of effective root-feeding zones, plant nutrients, bulk density, available moisture-holding capacity and other moisture relationships, heat absorptive power, specific heat, thermal conductivity, and soil aeration.

Agro-meteorology: To predict the possibilities of crop production in any specified area, it is essential to have adequate meteorological data, as well as a knowledge of the response of crops to given climatic environments. This may appear to be a simple thesis but it involves many problems. From recent investigations it appears that five meteorological observations are essential: temperature in exposed site, wind speed in exposed site, total daily solar energy (direct and diffused), vapour pressure in exposed site, and rain and snowfall. These observations should reflect conditions existing in the air moving over a region, and should not reflect the influence of local characteristics of soil and plant cover. The modifying influence on the climate of such local characteristics is often of great practical importance, but measurement of their effect throughout a region is impracticable because of the numerous combinations of conditions which may exist.

To make full use of meteorological data, studies must be made on the heat and energy requirements of plants, their moisture requirements, and their photoperiodism. The integration of these measurements with meteorological factors in order to solve the main problem may in itself be difficult but not impossible.

Agriculture

Methods of crop production: In some parts of the Subarctic, crops are grown successfully by the intelligent use of common methods. Undoubtedly crops could be grown in some other parts if studies were made of special methods to be used where common methods fail. In the areas already being examined further work is needed on the value of summer fallow for moisture conservation, on suitable irrigation practices, on fertilizers for soils low in fertility, on the fertilizing value of local sources of organic matter, on tillage practices, and on methods of protecting vegetable crops from summer frosts.

Plant selection and breeding: The selection, breeding, and testing of crops adapted to far northern conditions require continuous research which is of utmost importance in extending agriculture northwards.

Quality of crops: The quality of crops which have been grown in the north for human and livestock consumption appears to be satisfactory although

precise information is lacking. Information on the quality of indigenous fodders for livestock is also needed.

Livestock: Horses, cattle, poultry, and swine have been raised and maintained in a number of places in the Subarctic. However, investigations on their response to different environments and their feeding and care under varying conditions are necessary.

Research on soils and agriculture in as vast a region as arctic and subarctic Canada is costly, laborious, and slow. The federal Department of Agriculture is carrying out certain investigations in these fields in the north, but there is room and need for other research organizations and for individual scientists to become actively interested in studying these important problems.

In conclusion, it should be remembered that valuable information on soils and the agricultural possibilities of a region may also be obtained from the experience of resident gardeners and farmers, and from meteorological, geological, botanical, and other scientific data on the region. In fact, our present knowledge of the Arctic and the Subarctic is based largely on such indirect sources of information. The validity of inferences which can be made from this information depends largely on the number and variety of places where direct investigations on soils and agriculture serve as control points.

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WILDLIFE RESEARCH IN THE NORTH AMERICAN ARCTIC

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The civilized world has always been interested in the animal life of its frontiers. This is no less true of the arctic frontiers of our civilization than it was for the hinterland of the Graeco-Roman world. In part the interest is commercial; the whalebone whales and the walrus were followed from civilized shores to their arctic home waters, and the merchants who had sought sea routes to the orient soon contented themselves with new sources of furs. The gyrfalcon was commercialized for falconry in the middle ages, and the Greenland gyrfalcon was specially prized. Its unavailability at the end of the fourteenth century is a witness to the decline of the Greenland colony. As the falcon trade preceded recorded exploration, so the fur trade preceded scientific investigation.

There has also been from the beginning an element of curiosity, which is the foundation of science. Early naturalists speculated on how animals lived in the Arctic, and explorers left a series of incidental notes, which modern investigators can find only by reading their whole narrative. Barents, for instance, the first explorer in the modern sense, wrote an account of the toxic effect of polar-bear liver which is a model of reporting and could preface any biochemical or physiological dissertation on the subject.

Although it is impossible to separate biological research into compartments a classification can be made with some historical and logical warrant, provided the overlap is not forgotten.

The faunal inventory

The first task of the scientist was an inventory of the arctic birds and mammals showing the different specific entities, their geographical variations, and their distribution in space and time. This task is far from complete, and continues now with the more detailed concept of the ecological inventory, in which distribution is expressed in terms of numbers, and habitat or environmental preference. The catalogue of species is just about complete; one may expect some animals now called species to be reduced to synonomy, but the chances of new entities being discovered are very limited. However, an undoubtedly new bird species was discovered in Florida in 1918 (Howell, 1919), six years after Chapman (1912) remarked that no new species had been found in eastern North America for twenty-five years. Although this discovery was hailed as a marvel, still another bird, apparently qualifying as

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a new species, was found twenty-eight years later (Haller, 1940), in the eastern United States. Either speciation still goes on, or species still hide out, or both.

A recognizable and acceptable stage will have been reached when reasonably complete series of arctic birds and mammals are available in institutional collections, so that those wishing to study any group can do so with little trouble, and monographs dealing with the larger regions are published. We are far from that goal now. In a broad sense, the inventory is interminable, for evolution, including such events as the invasion of great areas by the coloured fox (*Vulpes fulva*), may always intervene to prevent any inventory from coming to an end.

The scientific study of wild animals became established on an organized basis about the same time that mapping of the Arctic began to be worked out systematically, and settlements were made in Greenland and Hudson Bay. Zoologists both solicited collections and sent out collectors; and in the course of time they themselves were able to go on organized expeditions.

Through members of the Royal Society who came into contact with patrons standing high in the councils of the Hudson's Bay Company, officers of the company sent home splendid collections. Their contribution is described by Baillie (1946). Alexander Light, James Isham, Andrew Graham, and Humphrey Marten may be mentioned as officers who became scientific collectors. Thomas Hutchins was a scientist who became an officer of the company. Samuel Hearne was an officer who attained recognition from scientists. It is nowhere indicated that the company suffered through this digression from fur trading. At a later date the same technique was used by the Smithsonian Institution to get collections from the Mackenzie area. The lamentably brief pioneer field collection efforts of Robert Kennicott (Chic. Acad. Sci., 1869) aroused the interest of seasoned company traders and the contact thus made was continued by Spencer F. Baird. Tradition has it that the Smithsonian sent barrels of rum, in which specimens were to be pickled, and received from the grateful traders, not pickled animals, but well prepared specimens of birds and mammals. One of these traders, Roderick MacFarlane, published important original reports.

The more important scientific exploring expeditions made natural history collections, and took scientists into the Arctic. Preble (1902, 1908) and Osgood and Bishop (1900), who made field collections for the U.S. Bureau of Biological Survey, also performed the very important service of listing and compiling the contributions of all their predecessors. Since that time there have been additional compilations on the fauna of arctic Canada (cf., Anderson and Taverner *in* Bethune, 1934). Many references may be found in a paper by the writer (Clarke, 1940).

It hardly seems right to dismiss the pioneer zoological collectors of the American Arctic with a summary reference to the compilations where their works are listed. Many of them were scientific adventurers in the highest sense, working with a minimum of outside aid and financial support and yet doing work which would have been a credit to the most luxuriously equipped

parties. One thinks especially of Kumlien in Baffin Island, of Hantzsch who perished in west Baffin Island, of Frank Russell in the Mackenzie area, and of the first Stefansson–Anderson party on which R. M. Anderson did the zoological work. These are merely outstanding examples.

A remarkably complete list of Greenland mammals was given in "Kongespejlet" (King's Mirror) written in the thirteenth century ('Grønl. Hist. Mindesm.' Vol. 3, pp. 326–9), which also includes Ivar Baardson's (pp. 248–64) account of the game in Eystri Bygd, and even the earlier sagas had enumerated the principal birds and mammals ('Grønl. Hist. Mindesm.' Vol. 1, p. 205). The missionary, Hans Egede, may be said to have recommenced the process, and O. Fabricius's monumental 'Fauna Groenlandica' (1780) antedated any comparable work covering other areas with which we are concerned. We now have monographs on mammals and birds by Winge (1898, 1902) and still later on birds by Salomonsen (1950–1). In addition, the Fifth Thule expedition extended Greenland investigations to Canada, and made some contributions to the inventory of its fauna.

The Russian occupation of Alaska began with a faunal report by Steller, to which the ensuing years of Russian occupation added little. On the other hand the zoological work of Kennicott antedated the United States' purchase, and was merely the forerunner of a long series of faunal investigations by both public and private institutions. Recent work by the Arctic Health Research Center at Anchorage has just about completed the inventory on mammals of arctic Alaska (Rausch, 1953). Bailey's 'Birds of arctic Alaska' (1948), however, was written before many collectors had penetrated interior areas such as the Brooks Range and may need additions.

Unfortunately the bird and mammal section of the 'Report of the Canadian Arctic expedition, 1913–18', was never published. The collections have long been available at the National Museum of Canada, and have been used in the preparation of many publications. The same cannot be said of the Ungava Peninsula collections accumulated during fifty years by the Carnegie Museum at Pittsburgh, under the leadership of W. E. Clyde Todd. There has been no preliminary publication and a complete work has yet to appear. Some valuable notes on mammals, and a few studies of birds have appeared, but the bird collection is not yet available *in toto* to other workers.

For those whose interest is primarily in the faunal inventory, Alaska and Greenland offer little new ground for field work. At the present stage collecting is best repaid in little known areas of Canada. It must, however, be admitted, that the bulk of Greenland collections are in Denmark, and larger Greenland collections in North American institutions would be welcomed.

In Canada there are only five good basic collections from the whole of the Yukon Territory, these being from the arctic coast, the former Canol Road, and the Alaska Highway. In the Northwest Territories it would be possible to describe the ranges of birds species well, and of mammal species fairly well. There are good collections from the whole arctic coastal zone east to Coronation Gulf, and from the Mackenzie delta, the Great Bear Lake area, Wood Buffalo National Park, Southampton Island, and Baffin Island.

Parts of Ellesmere, Melville, Devon, Banks, and Victoria islands are represented in collections, and collections have been made at all of the newer meteorological stations.

Virgin collecting territory on the arctic mainland of Canada west of Hudson Bay, is only a few miles from the coastal and inland settlements on navigable waters, and from the shores of the navigable waters themselves. Incidental collecting done in the past by exploring or administrative parties, affects the usefulness only of similar efforts, and not of really systematic collecting. Exceptions to this are all areas south of Great Slave Lake, and two areas to the north: the Anderson River where MacFarlane made a thorough collection ninety years ago, though it does not survive in such a state that it could not well be repeated, and the Nueltin Lake area, recently surveyed by Harper (1949). It is doubtful if there are as many specimens available from Yellowknife, the principal settlement in the territories today, as the early Hudson's Bay men, and Preble after them, collected at the old and new sites of Fort Rae. Such interesting areas as, for example, several mountain regions both on the east and west sides of the middle Mackenzie River, are unrepresented or poorly represented in collections, so also are Wager Bay, Bathurst Inlet, the Peel River above Fort McPherson, and the mountains west of Aklavik. Again, there are large areas around Contwoyto Lake, and the Back, Thelon, and Dubawnt rivers without any really useful collection.

In the arctic islands points of zoological interest still remain to be cleared up on Baffin Island, although more collecting has been done there than elsewhere. Prince of Wales, Bathurst, and Borden islands, and the north part of Victoria Island are areas of obvious interest, in the light of available information on their geology and topography. The possibility of linking up what is already known about Baffin Island and the western mainland coast with the many unknowns to form a solid body of knowledge, is still out of sight.

Life history studies

The study of the lives of arctic birds and mammals on a systematic basis is just beginning. Fragmentary data that have resulted from reconnaissance trips and collections show that each species has peculiarities that can be related to the arctic environment. Studies of lemmings, ground squirrels, and a whole series of arctic birds are well advanced in Alaska. Hanson and Smith's (1950) completed study of Canada Geese extends from the Arctic to the southern states. An equivalent study of the Golden Plover might extend from Alaska to Patagonia. Tinbergen's monograph (1939) of the behaviour of the snow bunting is a noteworthy example of what can be done in the Arctic.

The dramatic searches for the nesting grounds of the Blue Goose (Soper, 1930), Ross's Goose (Cartwright and Gavin, 1940), and Bristle-thighed Curlew (Kyllingstad, 1948), are reminders of the incompleteness of arctic knowledge. Equally important information remains to be learned about most arctic species. Tinbergen's work on the snow bunting is the barest beginning in the study of the behaviour of arctic birds. It is in the great breeding colonies of the north that the studies by Heinroth and Lorenz on the behaviour of geese and ducks

could be followed up most profitably. Sea-bird colonies offer unrivalled opportunities for behaviour studies and even the passerine Lapland Longspurs live closer to each other than the passerine birds to the south.

For the mammals we have Murie's (1944) wolf behaviour studies, but little else. Nothing has been done on the foxes: for instance what is behind the expansion of the coloured fox, and how does this affect the arctic fox? It is surprising that the life history of such a social animal as the caribou has not been the subject of special studies, though many workers have dealt with the species in a general way, and have made comments on practically every phase of its life history, working from a basic interest in numbers (cf., Banfield, 1951). The social behaviour of the muskox would also make a worthwhile study. The volume of general information that can exist without any full knowledge of the animals concerned is illustrated by Dutilly's (1949) 'Bibliography of reindeer, caribou, and musk-ox', which lists 2,422 titles. The larger bears must be studied soon or the opportunity may be lost, and among the birds, the least hint about Whooping Cranes[1] and Eskimo Curlews should be followed up immediately.

Animal populations

It has already been noted that the modern conception of an inventory of animals involves numbers and local distribution. Numbers are dynamic and fluctuate in both time and space. Populations of various species are interdependent. The arctic winter, itself severe, restricts the resources available so that animals must leave, like most birds, or adapt themselves. One of the most characteristic features of arctic animal populations is the great variation in numbers from year to year.

The question of periodic fluctuations in numbers of northern animals was perhaps the first matter beyond the cataloguing of the fauna to receive attention. Bernard Ross of the Hudson's Bay Company drew attention to it (Coues, 1877) and so did his contemporary, Roderick MacFarlane, whose comments were published at a much later date. Seton (1911) made the first clear statement of the problem. It was left to Charles Elton's Bureau of Animal Population (Chitty, 1950; Elton, 1942) to initiate and carry out detailed studies. The records of the fur trade were used as a statistical base, and year-by-year records were obtained from residents in the Arctic. We now have a substantial outline of the population cycles of arctic mammals and birds. Most of the details are lacking and can only be filled in by field work in the north, and especially by large-scale marking of individual animals. No other biological problem is more important or more challenging.

Animal disease and parasites

The *Parliamentary Papers* of Franklin Search days contain a dissertation on "Eskimo dog disease" (Ninnis, 1878), which is still a serious problem in the

[1]Since this account was written the nesting grounds of the Whooping Crane have been found in Wood Buffalo National Park.

north. This disease, or at least one of its forms, has now been identified as rabies (Plummer, 1947 a,b). Animals suffering from "dog disease" have been found to have typical Negri bodies in the brain, but there appear to be significant peculiarities that await study. Further investigation will become easier as laboratory facilities expand. At the moment it is still not known how many epidemic dog-wolf diseases there are in the Arctic, though certainly there are more than one.

It has already been shown that the Arctic may be a proving ground for the study of human immunity to disease. Already attention has been drawn to poliomyelitis, as records have become available of the progress of epidemics. The possibility that wild animals play a part in spreading some diseases becomes more apparent in sparsely settled areas. A recent disastrous beaver epidemic in Ontario was found to be due to tularemia of a type in which initial cultures are difficult to make (Labzoffsky and Sprent, 1952). A coincident blood testing of local Indians showed a number of persons with high titres, but there was no history of sickness.

Obviously the diseases of wild birds and mammals require more general study. The human link may be unsuspected, or indirect. The epidemiology of any disease casts light on human disease, and information about diseases of wildlife suggests new ideas to the medical profession. Also, diseases may be very important in the natural fluctuations of wildlife species. Some wildlife diseases which have not been studied in the American Arctic, like the virus diseases of colonial sea birds, may demand attention. Others now unsuspected may be more important.

Parasites are of major importance in the life of arctic species. Not unnaturally, those that might affect man have been the first to be studied. Trichinosis has long been known (Connell, 1949), but it was the dramatic account of its effect on a German task force that principally directed attention to it. It is being actively studied by the various health units, and may be expected to reward investigators for a long time to come.

Another parasite of potential importance is the tapeworm which causes hydatid disease. It is present as an adult in dogs and wolves throughout the north, and the cysts are to be found in ungulate game and domestic reindeer, with serious consequences to the health of these animals. In some subarctic regions of the Old World the disease is important to man. There are serious infections in North America, but admittedly the incidence is very low in view of the obvious possibility of universal infection. The complexity of the problem, the extent of the present studies, and the large field for future investigation is apparent from the writings of Rausch (1952), Sweatman (1952), and Miller (1953).

Physiology of birds and mammals

The recent availability of laboratory facilities has made possible the study of certain physiological problems which are linked with life in the Arctic. The principal questions are concerned with insulation from cold and fat

metabolism. Obviously these have a significant bearing on human accommodation, and in this respect the Eskimo has been rightly considered, in the metabolic and psychological sense, as a well-adjusted arctic race (*see* Krogh and Krogh, 1913). Reference may be made to a paper by Musacchia and Wilber (1952) on the arctic ground squirrel, which shows what is now done with good laboratory facilities, and to work discussed by Irving at the 1951 Alaskan Science Conference (1951) on the resistance to cold of the extremities of animals, including tiny birds. He showed that interesting comparisons of the fat properties and the insulation of tissues in tropical and arctic species had also been made. More recently, Irving (1953) has given a still further report on his work.

Barents' experience with polar-bear liver has been repeated many times. Rodahl's study (1949 a,b,c, 1950) of arctic vitamin sources and the discovery that the liver was so rich in vitamin A that it was toxic was made in east Greenland.

Administration

It is unfortunate that North American biologists have taken so little advantage of the facilities of the Danish Arctic Research Station at Godhavn. Established in 1906, it has always been prepared to accommodate research workers in all fields of biology. It has not much modern laboratory equipment, but it is always reasonably well supplied and has a magnificent library. There are many problems that could well be studied there.

The Canadian Government may be said to have first extended its work north when, in 1884 (Gordon, 1885), it chartered the steamship *Neptune* to take a scientific party to Eastern Arctic waters. Similar expeditions were made at intervals thereafter and have been made annually since 1922. The principal purpose has been to resupply government establishments, but in many instances scientists have been invited to make the trip, with valuable and stimulating results to arctic research. In 1950 a new government ship, the *C. D. Howe*, was commissioned, and remains the carrier of the official Eastern Arctic Patrol, though a variety of transport is now available to scientists. Air service to the Eastern Arctic did not start until late in the Second World War, but aircraft have been used for transporting zoologists in western areas since about 1930 and from about 1937 most have reached their main base by this means.

Land explorations moved north in 1887–8 when a survey under H. Dawson, of the Geological and Natural History Survey, and W. Ogilvie, of the Topographical Surveys Branch (Dennis, 1892), worked in the Yukon and Mackenzie regions. Collections and notes of vertebrate animals were made.. The progress of government surveys has been continuous since that year. The Canadian Wildlife Service now functions as a fact-finding agency in the Canadian Arctic, with officers stationed at Fort Smith, Yellowknife, Aklavik, and Churchill. This is a most valuable development, because active research is now carried out on most of the economically important species. Such an agency, however, is not designed to handle many fundamental research

problems and should be able to look to others for certain types of basic information. Within its proper field it is already producing a series of useful reports which will amount to a formidable contribution to knowledge in the course of time.

Wildlife investigations and management in Alaska have been the function of the U.S. Fish and Wildlife Service, formerly the Bureau of Biological Survey, which sponsored Osgood and Bishop and subsequent workers. In recent years the service has carried out active management with members of its staff stationed in Alaska.

All efforts at wildlife research in the Arctic by persons based outside come to a stop whenever experimental work is needed. This stage requires facilities for year-round residence and a fully equipped laboratory plant. It is the laboratory that is the critical factor, because living quarters are generally available. The first properly equipped laboratory to be set up in the Arctic since the Danish station in 1906 was the Arctic Research Laboratory at Point Barrow, Alaska, established in 1947 under the auspices of the U.S. Office of Naval Research. It is the first, and still the only, laboratory in the North America Arctic available for the study of the biology of arctic animals on a broad basis. The first studies carried out were those of Irving and the Swarthmore group on metabolism of arctic animals; other studies on terrestrial vertebrates are listed by Shelesnyak (1948) and in *Arctic* (1952, 1953).

The University of Alaska, at College, near Fairbanks, was at first designed to stimulate training in mining engineering. It was not until early 1950 that research in vertebrate zoology started. The stimulus in this case was the establishment of the Alaska Cooperative Wildlife Research Unit at the University under Neil M. Hosley. In such units, of which there are a number in continental United States, the U.S. Fish and Wildlife Service supplies a leader and a coordinated program while the State, the University, and a private foundation, the Wildlife Management Institute, supply space, equipment, facilities, and funds. Dr. Hosley had not been long at College when he became dean, and he was then succeeded as unit leader by John Buckley. Under their leadership, and that of Brina Kessel, of the University, important studies of birds and mammals have been carried out.

The Arctic Health Research Center at Anchorage is likewise not primarily concerned with feral vertebrates, but the possible importance of other animals in human health and the general interest of arctic animals has been recognized in research by Robert Rausch and other members of the staff. The same could be said of the Arctic Aeromedical Laboratory at Ladd Field, where the staff have an intense interest in the physiology of arctic animals.

In Canada there is only one laboratory equipped for biological work, that of the Defence Research Board at Fort Churchill. As at Ladd Field and Anchorage, much of the research is carried out by staff members, but the facilities have frequently been used to assist other workers. Within the biological field the emphasis has been on invertebrate animals, but this is not inherent in the nature of the laboratory. The lack of laboratory facilities in the north is a major impediment to arctic wildlife research. Preferably, such

a laboratory should be a place where, in addition to its own research, facilities are provided at low rates for those who wish to work out their own problems.

It is impressive how many of the *ad hoc* problems in wildlife research, discussed in the Arctic Institute's *Bulletin* No. 1 (1946), have already been studied. Through its research program the Institute itself has sponsored about forty projects related to wildlife. The more basic ventures, such as the experimental study of population fluctuations once proposed by Elton, remain unattempted.

The completion of the faunal inventory, and the experimental study of animal fluctuations have been mentioned as requiring urgent attention. It would be tedious to list in detail the problems that could be studied in such a wide subject. Some have a high degree of urgency. The impact of commercial exploitation has already made itself felt on the game and fur-bearing species, and until their biology is adequately known it will not be possible to manage them intelligently. The productivity of the Arctic is low, a fact that is often masked by large aggregations of individuals, and wildlife resources may easily be depleted. They can make their proper contribution to the economy of the land only under scientific management. At least until a proper basis of management is found, the only safe practice is to keep large areas preserved from exploitation. Some large preserves may be needed for demonstration and research. They should be set aside now before ill-advised and disorderly exploitation makes it impossible.

Finally, there is a great need for publications. Much of the recent research cannot be properly discussed because it remains unpublished. It may be expressed as a principle that for every grant of funds for research there should be a corresponding provision for publication.

The writer is indebted to Dr. Ira L. Wiggins for a précis on the subject on which he has drawn freely. Any grave lacunae may be attributed to the breadth of the subject, and the narrowness of his personal knowledge.

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INVERTEBRATE RESEARCH IN ALASKA

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To the zoologists of the mid-nineteenth century the invertebrate fauna of Alaska was virtually unknown. Some specimens from coastal localities touched on by earlier expeditions had found their way into various European and North American museums, but much of this material remained unidentified and of all the invertebrate groups only the Coleoptera seem to have received critical study (Mannerheim, 1843, 1846, 1852, 1853). In the interior it was not until 1861 that the first significant collections were made at Fort Yukon by Robert Kennicott, working for the Smithsonian Institution. Kennicott returned in 1865 as chief of explorations on the Western Union Telegraph Company's expedition (James, 1942) but died the following year, and his work was continued by W. H. Dall, who sent back a wide variety of specimens to the Smithsonian Institution.

Towards the end of the century two expeditions made important contributions to our knowledge of Alaskan invertebrates. The International Polar Year of 1882–3 resulted in collections from Point Barrow (Ray and others, 1885) and the Harriman Alaska expedition of 1899 made the most intensive scientific study undertaken in Alaska by a privately financed expedition. The results of the latter expedition, published in fourteen volumes as the *Harriman Alaska Series* of the Smithsonian Institution, contain in volumes 8–14 the most important single source of information on the invertebrates of Alaska and the adjoining seas.

The Canadian Arctic expedition of 1913 to 1918 also made valuable contributions to our knowledge of the northern and western coastal regions as far south as Nome (reports published at intervals between 1919 and 1925). At much the same time the U.S. Bureau of Biological Survey sponsored an intensive study of the biota of the Pribilof Islands (McAtee ed., 1923), and the zoological specimens from the Katmai expeditions of the National Geographic Society in 1917 and 1919 were described in the *Ohio Journal of Science* between 1921 and 1925.

During the 'thirties systematists studied a number of invertebrate groups. Papers on the composition and distribution of land and marine molluscs were published by Berry (1937) and Eyerdam (1939); the spiders were studied by Gertsch (1934) and Chamberlin and Ivie (1939); dinoflagellates and ciliates from adjacent Bering Sea areas were discussed by the Russian authors Kiselev

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(1937) and Stepanova (1937), and revisionary works, such as Stone's (1938) paper on horse flies of the nearctic region, included Alaskan species, as did numerous short papers in which distribution and new species were recorded.

Thus, until 1940 research on the Alaskan invertebrate fauna remained the province of the systematist, and had hardly passed beyond the descriptive stage. The collectors who gathered the specimens and sent them to museums seldom had the time or facilities for careful observations on life history and ecology. However, Hadwen and Palmer's (1922) working out of the life history of the reindeer warble and nose flies, with recommendations for their control, and the unpublished studies of fly parasites of reindeer undertaken by E. C. Cushing and W. E. Dove from 1929 to 1931 were notable exceptions. Somewhat later Tulloch (1934) spent a season at Fox studying mosquito biology.

With the increasing military importance of Alaska, both during and after the Second World War, funds were made available for scientific research in many fields, and permanent research centres were established. In invertebrate zoology, emphasis has been directed toward quantitative studies on the biology of species and the broader problems associated with the biotic community, particularly those which affect the economy and health of the human population. The task of bringing together the scattered literature and identifying the numerous specimens collected during recent years is also progressing at an appreciable pace, but most of this work, as well as some of the studies in ecology and physiology, is being done by specialists outside Alaska.

In Alaska invertebrate research is being carried on from at least five centres: the Arctic Research Laboratory of the Office of Naval Research at Point Barrow has concentrated on pure research; the Arctic Health Research Center of the U.S. Public Health Service at Anchorage investigates all problems affecting public health; the Arctic Aeromedical Laboratory of the U.S. Air Force at Ladd Field, Fairbanks, is mainly concerned with the health of military personnel, but also supports basic environmental studies; the Alaska Agricultural Experiment Station at Palmer examines crop pests; and at the Alaska Cooperative Wildlife Research Unit of the University of Alaska studies have been made of invertebrates as sources of food for fishes and of their importance to game and fur-bearing animals. In addition to these year-round centres, there is the Alaska Insect Control Project, directed by the Bureau of Entomology and Plant Quarantine of the U.S. Department of Agriculture, with funds provided mainly by the U.S. Army, which has been studying biting Diptera since 1947, though without a permanent staff or fixed headquarters. Finally, there is the research of many private scientists working on their own problems.

Because of the large number of organizations and individuals concerned it is not practicable to give a survey of all the work that has been done or is now under way in Alaska. Invertebrate zoology is a discouragingly large field and directly involves other biological disciplines which are often treated independently. This paper will inevitably reflect my personal preoccupation

with entomology, and especially the problem of annoyance caused by mosquitoes and other biting Diptera. For the most part it will be confined to research accomplished after 1940.

Recent and current research

Insects

It has been stated that biting flies are one of the principal obstacles to the development of the north (Stefansson, 1921, p. 245) and this is certainly true in Alaska where mosquitoes and other biting flies are everywhere a source of annoyance. During years of maximum abundance, mosquitoes infest thousands of square miles in numbers scarcely credible to those who have not lived and worked in their presence. The problem is not medical in the sense commonly true in the Tropics, for in Alaska no diseases are known to be transmitted by mosquitoes. It primarily concerns their effect on manpower efficiency and their ability to harass the settler, his family, and livestock to a point almost beyond endurance.

As a result of work by the Alaska Insect Control Project in central Alaska and that by U.S. Navy entomologists at Umiat, the identity and distribution of the mosquito species in those areas are now well known, and the larval habits and time required for larval development have been established. Except for papers concerned with Umiat (Jachowski and Schultz, 1948; Knight, 1948) and a preliminary account by Jenkins (1948a), most of these data are still unpublished. Adult mosquito activity has also been investigated by the Alaska Insect Control Project: Pratt (1949) has reported on the correlation of activity data with several microclimatic factors, and Sailer (unpubl.) has shown that a correlation exists between mosquito abundance and accumulated precipitation which may make possible prediction of unusually large or small populations well in advance of adult emergence. Finally, studies of prehatching treatments, larvicides, and insecticides, the last applied over areas up to 100 square miles, have provided information on the cost, effectiveness, and practicability of various methods of control (Travis, 1949; Travis *et al.*, 1949, 1950; Wilson *et al.*, 1949), and the effectiveness of repellents has been tested under Alaskan conditions.

Information gathered by the Alaska Insect Control Project on black flies has been published in several papers. General aspects of the problem were covered by Sailer (1953). Jenkins (1948b) has written about their biology and a much more comprehensive paper covering this subject is near publication (Sommerman, Sailer, and Esselbaugh [1955]). A paper on adult taxonomy by Stone (1952) was followed by one covering the larvae (Sommerman, 1953). Jenkins (1948b) also treated the punkies and Wirth (1951) reviewed their taxonomy.

The health centres have also been responsible for work on biting flies. Since 1949 a group at the Arctic Health Research Center under the direction of W. C. Frohne has added much to our knowledge of their biology and control. Williams (1951) has written on the biology of the punkie *Culicoides*

tristriatulus Hoff.; Frohne has published on the life history and habits of the mosquitoes *Culiseta impatiens* (Wlk.) (1953) and *C. alaskaensis* (Ludl.) (1954) as well as on several other subjects pertaining to biting Diptera. Studies of the filth-breeding flies and their possible importance as vectors of disease have been made at the Arctic Aeromedical Laboratory. This laboratory has also supported an investigation of mammal ectoparasites by the Rocky Mountain Laboratory of the National Microbiological Institute.

At present the species of insects that cause injury to garden and field crops are limited in Alaska. However, as agriculture develops, more and more insects are likely to become of economic importance; for instance the first control operations against grasshoppers were made near Palmer in 1953. Research is mainly centred at the Alaska Agricultural Experiment Station at Palmer, where J. C. Chamberlin (1949) was the first agricultural entomologist to deal extensively with Alaskan insects. Measures to prevent the accidental introduction of foreign pests are the responsibility of the Anchorage Office of the Bureau of Entomology and Plant Quarantine.

Working from the Arctic Research Laboratory at Point Barrow, Weber (1950, 1953) has made studies of the arctic insect fauna and has listed about 350 species. In 1952 and 1953 P. D. Hurd was the entomologist on a project concerned with population biology of arctic land vertebrates at the laboratory, and in 1953 he also assisted in another project on the reciprocal relationships of vegetation and the physical environment in the tundra. He has obtained large collections and much information on the importance of insects as food for certain birds, and his observations of insect activity, when correlated with microclimatic data, should add much to our knowledge of the requirements and behaviour of insects living on the tundra.

Parasites

The Arctic Health Research Center and the Arctic Aeromedical Laboratory are investigating the high incidence of parasitism among animals and humans in arctic Alaska. Native mammals and other vertebrates have been found to be subject to extensive infestation by parasites that are actual or potential menaces to human health. Since meat is the most important part of the diet of man and of his principal beast of burden, the implications are obvious, and the subject requires careful study.

Trichinosis has long been known to occur in the Arctic, and recent work has shown this disease to be present in animals not previously suspected of harbouring the parasites. Connell (1949) has summarized our knowledge of trichinosis in the Arctic. Startling information about the incidence of hydatid disease has been published in the last few years, with the result that quarantine restrictions on the movements of dogs have been recommended. The present status of knowledge about the disease and the causal organism has been reviewed by Rausch (1952b) and Rausch and Schiller (1951).

The Arctic Health Research Center has also encouraged the parasitologists on its staff to study parasites of native animals whether or not they appear to threaten human health. Consequently, a number of previously unknown

species have been discovered and described, many of them by Rausch (1951, 1952 a,c) and Schiller (1952 a,b,c,d, 1953). Life-cycle studies are also being made, and the experimental infection of Alaskan gulls with *Diphyllobothrium* sp. has recently been reported by Babero (1953).

Ectoparasites of various kinds have been collected by J. M. Geary at the Arctic Aeromedical Laboratory, and papers recording hosts and describing new species have been published (Keegan, 1951; Keegan and Hedeen, 1952). The paper by Philip, Gill, and Geary (1954) on the role of the rabbit tick in the transmission of tularemia is of special interest.

Arachnida, Crustacea, and other non-insect arthropods

Much of the recent work in these arthropod groups has been taxonomic or distributional. Arctic Alaskan records for Arachnida have been listed (Weber, 1950), taxonomic studies of spiders have been published (Chamberlin and Ivie, 1947), and several new genera and species of mites have been described (Newell, 1949, 1950). Hammer (1955) has published an extensive paper on oribatid mites based on material collected by the Alaska Insect Control Project and by N. A. Weber. In 1953 J. L. Mohr and his associates at the Arctic Research Laboratory began a study of the ecology of arctic Crustacea; investigations by G. Comita of the fauna of an arctic lake near Point Barrow and by John Krogh of a lake near Anchorage (both unpubl.) should also provide useful information. Other published accounts include a paper by R. V. Chamberlin (1946) on Alaskan chilopods, and by Mrs. M. Stratton Wilson (1953 a,b) on the freshwater copepods.

Freshwater and terrestrial invertebrates other than arthropods and parasites

Many of these animal groups have been neglected during recent years, although much material has been collected and distributed to specialists. Among the few recent articles dealing with these groups, the account by Kenk (1953) on the freshwater triclads of Alaska is of general interest, as he found four endemic species that show no close relationship to the present North American fauna, but have unmistakable Eurasian relationships. Pronounced palearctic affinities have been recognized in other groups of the Alaskan fauna, and the probability that a land bridge between Alaska and Asia has existed more than once within comparatively recent geological time is well established. Nevertheless, Kenk's work with the freshwater flatworms has special significance because of the extremely limited mobility of these organisms. It is almost inconceivable that they could have reached Alaska except by way of freshwater streams. The absence of typically North American species of triclads suggests a degree of isolation from the nearctic fauna that would not be suspected from a casual study of a map or knowledge of present physiographic and climatic conditions.

Marine invertebrates

Most of the recent work on marine invertebrates has been carried on from the Arctic Research Laboratory in the waters near Point Barrow, and particularly by G. E. MacGinitie, when he was director of the Laboratory. His

interests were primarily ecological, and many data were obtained on the environmental requirements and behaviour of arctic marine invertebrates. He and his associates also made large collections, which are now being studied by taxonomists, who have already published some papers (Coe, 1952; Pettibone 1951), of which Loeblich and Tappan's 'Studies of arctic Foraminifera' (1953) is the most extensive and also contains much ecological information.

Problems and opportunities for research

Ninety-five per cent of all the animal species in Alaska are invertebrate. Obviously any attempt to enumerate or delimit the problems concerned in so vast a field would serve little purpose for the investigation of any one problem would almost always result in the discovery of others. For example, I will mention a few of the new problems I found in my own attempts to learn something of mosquito and black fly ecology. Why should 2,441 *Aedes communis* (DeG.) mosquitoes with a sex ratio of two males to one female emerge from 4 square feet of pool surface when only 590 mosquitoes of the same species with equal numbers of males and females emerged from the same area of another pool a few feet away? What is the explanation for the variation in colour and structure that makes identification of females of many Alaskan *Aedes* so difficult? The latter question has many ramifications, for detailed information on pest importance and flight-range of species depends upon easy and accurate identification. Why should the black fly *Simulium venustum* (Say) bite viciously at Kotzebue and fail to be recorded as a biting species in other parts of Alaska? And why should some black fly species aggressively attack man late in September and in October but not in mid-summer? In mid-summer they will not even fly except when the temperature is much higher than that recorded during flight activity in the fall.

The parasitologists are rapidly learning what parasites inhabit various species of vertebrates, but questions regarding life cycles are largely untouched, and almost nothing is known of the part parasites play in the population cycles of their hosts. Taxonomists have been enumerating species and recording locality data for many years, but the task of collating these data in such a way as to throw light on Alaska's key position in the zoogeography of the holarctic region has hardly been begun. Ecologists have made comparatively few studies in Alaska yet the geographic position and physiography combine to produce a variety of climates and habitats unmatched in other arctic and subarctic regions. Regional differences are great and sharply delineated, and within each region the precipitation and temperature differ markedly from year to year. These factors contribute toward making Alaska an ideal laboratory for studying the underlying principles of ecology.

Future research could most profitably concentrate on ecological information useful to conservationists and game-management workers. This should include careful studies of the terrestrial and aquatic faunas, for fishing, trapping, and hunting are and should continue to be an important part of the economy. The rapid growth of agriculture will inevitably necessitate greater attention

to crop pests and means for their control. Mosquitoes, black flies, and punkies continue to be a serious problem, and every effort should be made to obtain better means of control, at a lower cost. Also, recently increased interest by pulp and lumber industries in the huge forest resources of Alaska has shown a need for greater knowledge of the forest pests. In 1953 a survey by the Bureau of Entomology and Plant Quarantine revealed that an outbreak of the black-headed budworm extended over practically the entire Tongass National Forest in southeastern Alaska, an area of 16,073,000 acres; an epidemic infestation of the hemlock sawfly extended over approximately 4,000,000 acres in the southern part of the same forest, and bark beetles have killed many Sitka spruce in past years. In the face of diminishing forest reserves, insect-caused losses become increasingly important and can be reduced only by better knowledge of these pests gained through long-term, carefully planned research.

Above all it is essential for the future welfare of the country that the present research centres be maintained on a permanent basis with sufficient funds to carry out studies that will add to our knowledge of how to live prosperously under the rigorous and varying conditions characteristic of Alaska.

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PRESENT TRENDS AND FUTURE NEEDS OF ENTOMOLOGICAL RESEARCH IN NORTHERN CANADA

T. N. Freeman* and C. R. Twinn†

Part I. The Northern Insect Survey. By T. N. Freeman[1]

The study of insects of northern Canada has in the past depended mainly on a very small number of collections, some obtained on early expeditions searching for the Northwest Passage, and others taken incidentally on subsequent expeditions. The work of Kirby (1837), the reports of the Canadian Arctic expedition (Hewitt, 1922) and of the Fifth Thule expedition (Henriksen, 1937), and a few short papers represent the main contributions for many years.

Organized entomological research in northern Canada began in 1947 as a joint project of the Defence Research Board, Department of National Defence, and the Entomology and the Botany and Plant Pathology divisions, Department of Agriculture. The research program was divided into three major phases as follows: (1) investigations on life-history, habits, ecology, and control of biting flies by the Veterinary and Medical Entomology Unit; (2) the Northern Insect Survey, which deals with systematics, distribution, relative abundance, and ecology of biting flies and other insects, by the Systematic Entomology and Botany units; and (3) investigations on laboratory rearing techniques for northern mosquitoes, and on behaviour and systematics of some mosquitoes of the genus *Aedes*, by the Defence Research Board at the Defence Research Northern Laboratory, Fort Churchill, Manitoba.

During the past ten years, some insect collections have also been made by officers of various government establishments scattered throughout the north, and by individuals supported by grants from the Arctic Institute of North America.

In this paper only a brief summary of the work accomplished can be given, and the writer's views are noted on areas that require investigation and on lines of study that should be emphasized to give a better understanding of the origins and present composition of the northern insect fauna. A short list of references notes the more significant publications that have appeared to date.

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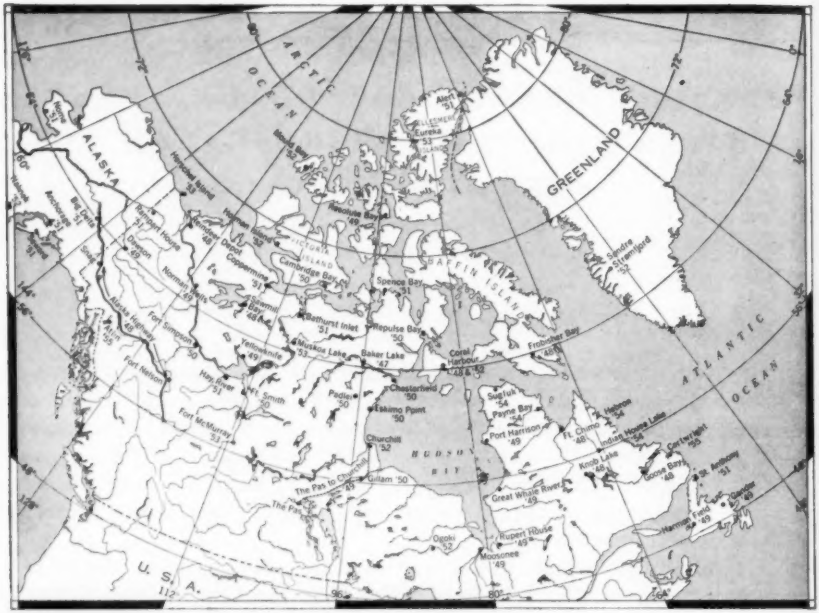
ARCTIC OCEAN
ALASKA
GREENLAND
BAFFIN ISLAND
ATLANTIC OCEAN
HUDSON BAY
U. S. A.
Alert
Eureka
Resolute Bay
Spence Bay
Cambridge Bay
Bathurst Inlet
Repulse Bay
Baker Lake
Coral Harbour
Frobisher Bay
Chesterfield
Whale Point
Churchill
Padlei
Fort Smith
Fort McMurray
Fort Nelson
Fort Simpson
Norman Wells
Aklavik
Inuvik
Barrow
Point Hope
Kotzebue
Nome
Anchorage
Big Delta
Whitehorse
Dawson
Mayo
Ross River
Watson Lake
Hay River
Peace River
Edmonton
Prince Albert
The Pas
Gillam
Great Whale River
Port Harrison
Payne Bay
Sagluk
Ft. Chimo
Hebron
Nain
Knob Lake
Goose Bay
St. Anthony
Battle Harbour
Harrington Harbour
Labrador
Seven Islands
Moosonee
Rupert House
Oxford House
Island Lake
Berens River
Norway House
Cross Lake
Sioux Lookout
Kenora
Fort Frances
Port Arthur
Sault Ste. Marie
Sudbury
North Bay
Ottawa
Toronto
Hamilton
Buffalo
Detroit
Cleveland
Chicago
Milwaukee
Minneapolis
Duluth
Winnipeg
Regina
Moose Jaw
Swift Current
Medicine Hat
Calgary
Edmonton
Prince George
Vancouver
Victoria
Seattle
Portland
San Francisco
Los Angeles
San Diego
Salt Lake City
Denver
Omaha
Kansas City
St. Louis
Memphis
Atlanta
Charleston
Jacksonville
Miami
New Orleans
Houston
Dallas
El Paso
Albuquerque
Phoenix
Tucson
Las Vegas
Reno
Boise
Billings
Bismarck
Fargo
Grand Forks
Pierre
Rapid City
Cheyenne
Scottsbluff
Lincoln
Des Moines
Davenport
Peoria
Springfield
Indianapolis
Cincinnati
Columbus
Pittsburgh
Buffalo
Rochester
Syracuse
Albany
Boston
Portland
Bangor
Halifax
Saint John
Quebec
Montreal
Ottawa
Toronto
Kingston
Windsor
Detroit
Cleveland
Chicago
Milwaukee
Minneapolis
Duluth
Winnipeg
Regina
Saskatoon
Edmonton
Calgary

Adelaide Peninsula, is not known. The other areas from which collections are required are in the northeast and east. In Baffin Island material is needed from the north and central parts, from the east coast, especially at Clyde, and from the south coast, particularly near Cape Dorset, as the scanty material so far obtained from this coast indicates a rich fauna of parasitic Hymenoptera. In Labrador the Torngat Mountains should be studied. The relict insect fauna in the Gaspé region should be further investigated and also compared with that of the high elevations on Mt. Katahdin, Maine, and Mt. Washington, New Hampshire. Much more work and material are needed from the higher elevations in central Newfoundland. Many smaller gaps also exist between areas that have been investigated; the relative importance of these should be revealed as progress is made on the distribution studies of the major groups.

Many problems are of a broader and more fundamental nature. Survey data suggest that mosquitoes do not occur north of the mean July isotherm of 35°F. Also, the adults apparently emerge approximately four weeks after the mean temperature for 14 days reaches 34°F. The latter observation is based on a correlation of weather data and mosquito emergence from 14 localities across the north during the past six years; observations were made at each locality for one season only and additional correlations are required. If these observations are well founded, the dates of mosquito emergence can be predicted four weeks in advance.

Problems of distribution are very complex. Along the Mackenzie River the boreal forest and boreal insects penetrate almost to the Arctic Ocean. There the effect of the continuous summer daylight on behaviour, particularly of those nocturnal species whose distribution extends southward into the regions of regular day and night, should be investigated, and may help to explain distribution patterns elsewhere. Many of the arctic insects intrude on the northern fringe of the boreal forest, and some boreal species intrude on the arctic region, for example in Bathurst Inlet, although Freeman (1952a) has postulated the principle that arctic and boreal insects are specifically distinct. The extent of these intrusions from one zone to another is not well known or understood. When they are mapped it may be possible to define the Northern Transition zone more precisely. Distribution patterns may be dependent, to a greater or lesser degree, on the soil types and underlying rock formations; for instance, the North American subspecies of *Papilio machaon* Linn. appears to be restricted to those regions in the Northern Transition zone where the granitic Canadian Shield dips under the sedimentary Paleozoic and Mesozoic formations. The adaptation of insects in relation to the absence, presence, or nearness to the surface of permafrost should also be investigated. An ecological study, perhaps at Churchill, might assist in solving some of these distribution problems.

Other major problems include a study of the origins and postglacial histories of the arctic species, and how they are related to botanical views on plant distributions and origins. There is a great need for Siberian material in this study. The origin of the unique Greenland fauna, which consists of nearctic and holarctic species in northern Greenland and palearctic boreal

species in southern Greenland although there is no forest, should be investigated. Boreal species of insects also predominate in the treeless areas of the Aleutian Islands, where arctic species would be expected. Perhaps the Aleutians and southern Greenland have some factors in common that are responsible for this unexpected distribution.

All of these perplexing problems point to the need for studying the insect fauna of the Subarctic and Arctic as a whole rather than on a regional basis.

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Part II. Biology and Control of Biting Flies. By C. R. Twinn[1]

Results of biological and control studies of biting flies in northern Canada, carried out by the Veterinary and Medical Entomology Unit of the Entomology Division and associated agencies, have been presented in about 75 papers published in scientific journals or prepared for publication. Among these, two papers by Twinn (1950, 1952) review the investigations and the results obtained from 1947 to 1950, and give references to papers that were published or prepared for publication during that period. Much of the work and published results not included in those summaries are reviewed here.

In the study of the various species and of methods of combating them and securing protection from their bites, it would be very helpful if laboratory colonies of the insects could be maintained. So far, this is possible with few northern species, largely because of inadequate knowledge of their life-histories and habits. McLintock (1952) developed a method of rearing *Culiseta inornata* (Will.), a culicine species whose range extends into subarctic Canada. However, attempts to rear common northern species of mosquitoes (*Aedes* spp.) and black flies (Simuliidae) continuously in the laboratory have not yet been successful, and further attention should be given to this problem. Hocking and Pickering (1954) have described attempts to rear black flies at Churchill, and given records of the seasonal occurrence of 21 species of Simuliidae in northern Manitoba and observations on the life-histories and habits of some of them, especially *Simulium venustum* Say.

Of value in planning measures for control and personal protection are the results of a study on the dates of emergence of certain species of black flies in a series of localities, extending from south to north and from west to east in Canada (Ide *et al.*, in preparation). This study provided data on which the beginning of the black-fly season at various latitudes and longitudes could be predicted.

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Knowledge of the biologies of many of the species of biting flies of various genera that occur in the vast subarctic and arctic regions of Canada is still sketchy. Two recent papers, however, present data on the occurrence, relative abundance, ecology, and development of mosquitoes: one by Haufe (1952) on the species at Goose Bay, Labrador, and the other by Curtis (1953) on the species at Whitehorse, Yukon Territory.

Studies at Churchill on development, behaviour, and local distribution of mosquitoes in relation to meteorological conditions have been completed and a series of papers prepared. A preliminary paper on predicting peak dates of emergence of mosquitoes, based on some of this work, has been published by Haufe (1953). Knowledge of the distribution and behaviour of biting flies under various conditions is important in devising control procedures against the adult insects. Much information of value for this purpose has been obtained, but further study is needed of the vertical distribution of these insects and of their resting sites and resting behaviour, to ensure the most effective and economical use of insecticides.

In the north there are vast areas of permafrost where drainage is poor; mosquitoes breed in the surface pools that form in the spring, black flies in the run-off streams, and tabanids (moose flies and deer flies) in the muck and moss of the swampy forest floor. Under these conditions enormous numbers of the insects develop over thousands of square miles. Accordingly, it is most important in planning control measures to have knowledge of the dispersal habits and flight ranges of the various species. Because of the difficult terrain and lack of roads and other facilities in northern Canada, studies involving the release and recapture of marked specimens have been carried out in Saskatchewan. Methods of mass tagging of black flies with radiophosphorus have been developed by Fredeen *et al.* (1953a) and of mosquitoes by Shemanchuk *et al.* (1953).

Hocking (1953a) followed a different approach to the problem of insect flight range by studying the energy resources of some of the northern species in relation to their power requirements and efficiency in utilizing energy in flight. He concluded that northern biting flies obtain the energy for flight from the nectar of flowers, and by ingenious observations and experiments obtained data on which he based estimates of the maximum distances certain species might travel in still air and their possible maximum air speeds. However, there is still little exact information available on the distances most of the species may travel either in actual flight or with the wind, and the problem needs further investigation.

The nature of the poisons from, and the toxic effects of, insect bites have not been adequately studied. This information is essential in attempts to immunize individuals against the effects of insect bites. The subject is being explored but, so far, apparently with little success. If, as suspected, such immunity is restricted to a species or group of species, the problem is enormously complicated by the large number of different blood-sucking flies involved. Another approach is to seek methods of ameliorating the effects of the bites. O'Rourke and Murnaghan (1953), from studies at Ottawa of the

skin reaction to bites of *Aedes aegypti* (L.), reported that the application of a 2 per cent Pyribenzamine cream relieved the reaction and itching from mosquito bites.

Investigations on chemical control of biting flies have been largely confined to the subarctic and temperate regions of Canada. Control measures have been devised that are reasonably effective south of the tree-line against mosquitoes and black flies when properly applied over a sufficiently large area, the size of the area depending largely on local circumstances, such as species and topography. In area control of these insects with DDT applied from aircraft, a rotary brush unit is an effective and economical device for spraying large areas (Brown, 1952).

The development and use of DDT as a larvicide against black flies has been described (Twinn, 1950, 1952). Its use in controlling black flies in the Saskatchewan River from 1949 to 1951 was reported by Fredeen *et al.* (1953b). These authors (1953c) also reported that suspended solids in this river adsorb DDT, and suggested that the effectiveness for long distances of single applications of the larvicide in turbid water is due to the larvae ingesting the DDT adsorbed by the solids. Experiments at Churchill by Hocking (1953b) showed that a water suspension of heptachlor also gave excellent control of black-fly larvae at dosages as low as one-third of that required for DDT. No other promising materials were found.

Although practical methods have been devised for reducing local infestations of mosquitoes and black flies to negligible proportions about military bases and other centres of population south of the tree-line, high costs, lack of facilities, and transportation difficulties render them unsuitable for use where few people are involved. Area control is not feasible on the tundra because the mosquitoes, which are the major pest there, travel long distances, and treated areas are likely to become reinfested quickly. Accordingly, special attention has to be given to developing methods of local and personal protection both on the tundra and in the subarctic forest.

Application of aerosols and fine sprays from easily transportable ground equipment has value in such situations. In ground control experiments, chemical and biological assessments have been made of the performances of a number of machines for this purpose (Brown and Watson, 1953). However, there is need for further work on the effectiveness of insecticidal mists and aerosols under various conditions, and on the use and value of residual and barrier sprays applied to vegetation about campsites and similar situations.

Tabanids are often fierce pests in forested regions, especially in swampy areas, but fortunately they are not a problem on the tundra. In experiments at Goose Bay, Brown and Morrison (1955) found that lindane applied at 0.5 lb. per acre from aircraft was superior to DDT or dieldrin, and that it temporarily eliminated adult tabanids in open but not in dense forest. However, the value of chemical control methods against these insects, like the use of presently available repellents, is still doubtful.

Repellents are effective in protecting exposed skin surfaces against biting flies other than tabanids, and also in preventing insects from biting through

clothing that has been impregnated with these chemicals. The period of effectiveness of repellents on the skin is greatly reduced by removal of the material by sweating and by absorption through the skin, so that frequent applications may have to be made, especially by persons engaged in strenuous activities under warm, humid conditions. Furthermore, most repellent materials cause a stinging sensation when in contact with delicate tissues, such as about the eyes and lips, and in some individuals cause general skin irritation.

Studies are being made at Toronto and Ottawa (Roadhouse, 1953) to obtain repellents without these disadvantages. At Ottawa, laboratory screening tests of repellent compounds were facilitated by a method in which guinea pigs were used as the test animals (Kasman *et al.*, 1953). Advantages are that a smaller quantity of the repellent is required than when human subjects are used, it is less expensive and less time-consuming, and toxicity to the host is not a major consideration.

Devices for personal protection such as head nets have definite value. These, however, may interfere with vision, and often make the wearer hot and uncomfortable. Efforts have been made to improve the protective qualities of clothing, both in the choice of materials through which the insects cannot bite and of colours unattractive to them, and in the improvement of design to reduce exposed skin surfaces and to prevent black flies from having access to spaces between the clothing and the skin. The suitability of such clothing must naturally depend on the nature of the activities of the wearer.

A knowledge of the factors that attract biting flies to their hosts and stimulate them to feed is of value in solving the personal protection problem. A series of papers on the responses of female *Aedes* mosquitoes has been published, the latest of which is by Brown (1954). However, this subject is still inadequately understood and further work with species of the several groups of biting flies is needed.

The role of insects, nematodes, microsporidia, and other parasites and predators in the natural control of mosquitoes, black flies, and tabanids is being studied at Churchill and elsewhere, and a preliminary paper has been published (James, 1953). Progress in studies on the use of the precipitin test for determining predator–prey relationships has been reported by Hall *et al.* (1953). This serological method is also used to determine the source and rate of digestion of host blood in mosquitoes (West and Eligh, 1952).

Undoubtedly, natural enemies are of prime importance in reducing biting-fly populations but, although much has been learned about them, a great deal more needs to be known before their effectiveness can be increased by manipulation.

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RECENT BIOLOGICAL RESEARCH IN GREENLAND

T. W. Böcher*, K. Holmen*, and M. J. Dunbar†

Botany. By T. W. Böcher and K. Holmen[1]

Taxonomy

Vascular plants: The large amount of vascular plant material collected in southwest Greenland by the botanical expedition of 1946 has been published by Böcher (1952a), who has discussed several species in earlier studies (1950, 1951) and has written a monograph on *Carex Heleonastes-amblyorhyncha* in its entire circumpolar range (1952b). Material from other expeditions has been included in Sørensen's (1953) study of the difficult genus *Puccinellia*, and in his present research on the genera *Hierochloe*, *Calamagrostis*, and *Braya*, and in K. Holmen's systematic studies of the genus *Festuca*.

Our knowledge of the chromosome numbers in Greenland vascular plants has recently been advanced by a list of chromosome numbers of the Peary Land plants published by Holmen (1952), one conclusion being that the extent of polyploidy in that flora is not significantly higher than in other arctic areas, contrary to the theory that polyploidy should increase with worsening climatic conditions. A comprehensive review of the chromosome numbers in the Greenland flora, the work of a team consisting of C. A. Jørgensen, Th. Sørensen, and M. Westergaard, is approaching completion. T. W. Böcher is continuing his study of the *Arabis Holboellii* complex (1951), and has now included several North American races for comparison. In addition to cytological investigation, breeding experiments have established significant genetical differences between the Greenlandic and North American populations of the species. Cytological factors in the *Stellaria longipes* complex are also under study. Intensive research on the *Papaver radicatum* complex and other closely related species of *Papaver* is being carried out by C. A. Jørgensen.

There has long been a need for a concise handbook of the vascular plant flora of Greenland, and one is now being prepared by T. W. Böcher, K. Holmen, and K. Jakobsen. This handbook, which is designed for both teachers in the Greenland schools and for plant collectors, will list all the Greenland vascular plants and give their distribution within the country. The text will be in Danish, but there will be a foreword in English with

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[1]Text completed in 1953.

translations of the more important technical terms and a map of the floristic regions. An elementary botany in Greenlandic for school use, which will contain examples taken from the commonest Greenland species, is also planned by the same authors.

Bryophytes: Of all the plant groups, the bryophytes are the richest in species in Greenland. The principal source material, however, is still the collections made by S. Berggren and N. Hartz during the nineteenth century, and our knowledge of the group is fairly poor. The situation should soon be remedied, for since the Second World War comprehensive collections of bryophytes have been obtained from several areas. Thus K. Holmen made a study of the bryophytes round Søndre Strømfjord and Arsuk Fjord in west Greenland in 1946, and of Peary Land in the north and of Ella Ø and Clavering Ø in east Greenland in 1947–50. The Sphagnum species of this material are included in a work on all the Greenland Sphagna by Bodil Lange (1952), the Hepaticae by Eva Clausen and the Musci by K. Holmen will soon be ready for publication. Studies are also being made of the extensive material collected by K. Jakobsen from 1947–50 in the region between the Nugssuaq Halvø and Thule in west Greenland, and of smaller collections from other areas.

Lichens: The macrolichen flora of Greenland is fairly well known through the work of the Norwegian botanists B. Lynge, P. Scholander, and Eilif Dahl, but there is still much to be done. The large collections brought back by the Danish botanists M. Skytte Christiansen (mostly from Søndre Strømfjord and Arsuk Fjord in 1946), K. Holmen (from Peary Land in 1947–9), and K. Jakobsen (from the Nugssuaq Halvø in 1947, 1948, and 1950), is at present being studied by Christiansen, who has discovered several species of macrolichens not formerly recorded from Greenland in this material.

The microlichen flora is much less known. In the Scandinavian herbaria there are large collections of crustaceous lichens, but the determination of them requires an immense amount of microscope study, and the working up is a long process. Only a few genera, such as *Rhizocarpon*, are well enough known to permit phytogeographical discussion. At present the number of species with restricted distribution seems too large in proportion to the number of known circumpolar species. There is still a great amount of collecting to be done, but by trained lichenologists only, since a large number of crustaceous lichens are so inconspicuous that they may easily escape the notice of even experienced botanists.

Fungi: In the past, collections of Greenland fungi have been brought home by many expeditions. Most of the known species, however, were collected unintentionally on specimens of higher plants. E. Rostrup and J. V. Lind, who made a special study of herbarium specimens, have published a number of papers on Micromycetes found in this way, and our knowledge of the Greenland Micromycetes is probably fairly complete. Rostrup has also published scattered records of fleshy fungi, especially in his survey of 1888, in which most of the older records are summarized.

Comprehensive collections of Macromycetes and a study of their ecology were made in the Ivigtut, Godthaab, and Søndre Strømfjord areas in 1946 by M. Lange. Lange (1948) has also published a list of the Greenland Macromycetes which includes typical arctic species as well as elements of a steppe flora. In investigating the relationship of the Macromycetes flora, he found that the Greenland species tested were infertile with similar species from Europe and North America.

Algae: Recent publications include K. Holmen's collections of marine algae from Peary Land which have been worked up by Lund (1951), and the freshwater algae (Grönblad, 1952) and diatoms (Foged, 1953) collected by T. W. Böcher in southwest Greenland in 1946. Altogether 271 species were found in 42 samples from southwest Greenland, including several diatom species new to science. N. Foged is at present studying a series of diatom samples collected by Holmen in Peary Land, and his own large collections from the 1952 expedition to northwest Greenland sent out by the Commission for Scientific Investigations in Greenland. Also approaching publication are S. Lund's important collections of marine algae from Scoresby Sund and Ella Ø.

Plant geography

In southwest Greenland Böcher (1952a) found a significant floristic contrast between the coastal area and the inland region at the head of Søndre Strømfjord. In a local flora of 200 species of vascular plants there are 47 species which are absent or are very scarce in the coastal parts and 73 coastal species which become scarcer or are absent in the inland region. There is also a considerable difference between the vascular plant flora of the inland areas of Søndre Strømfjord and that of the more southerly Godthaab Fjord. It has been shown that a number of species which favour an Atlantic (maritime) climate have a limit of northern distribution running diagonally from the interior of Godthaab Fjord to the coast at Holsteinsborg, a line which coincides with the isohyets and with the lines of equal mean annual temperature range. On the basis of the observed floristic differences and the distribution maps for a large series of plants, it has been possible to divide southwest Greenland into floristic districts. Johannes Gröntved has also been working on the flora of southwest Greenland for many years, and during the 1953 season was collecting there with C. A. Jørgensen.

The comprehensive plant collections brought back by the Geological Survey of Greenland expedition to northwest Greenland will shortly be published by K. Jakobsen, who was responsible for most of the botanical collecting, and is preparing a local flora of the region between the Nugssuaq Halvø and the Thule district.

A local flora of the vascular plants of Peary Land is about to be published by K. Holmen, who has also found significant differences between the coastal and inland floras. Of some 90 species collected in that northernmost region by the Pearyland expedition of 1947–50, only 27 were previously known from the area.

In a recent report (Holmen and Mathiesen, 1953) describing the finding of *Luzula Wahlenbergii* in northeast Greenland, a species not known from Greenland hitherto, an analysis of the vegetation in which the species is found is included.

The distribution of mosses and lichens also has interesting features. K. Holmen's investigations in Søndre Strømfjord and Arsuk Fjord have shown that the composition of the moss flora varies greatly both from the coast inland and also from north to south. The lichen flora of southwest Greenland has recently been studied by Dahl (1950) who finds that the macrolichen flora there is almost identical with that of Scandinavia, a fact that can be explained by the survival of the flora on ice-free refugia during the last ice age. The North American element in the macrolichen flora of southwest Greenland is very small. A closer study of the lichens of the Rocky Mountains, and of the Ural' and Altai ranges, is still badly needed for an understanding of the relationships within the arctic lichen flora. K. Holmen's collections from Peary Land, according to Skytte Christiansen, indicate the presence of a high-arctic, arid element in the flora which Greenland has in common with Ellesmere Island. Christiansen's own collections from the continental areas in Søndre Strømfjord point to the appearance of a steppe or desert element in the lichen flora on loess soils on southern slopes.

Ecology

The work of the French botanist H. de Lesse in the Eqe region at the head of Disko Bugt (de Lesse, 1952) is an important contribution to our understanding of the vegetation of central west Greenland. He has discussed the eleven main types of plant community in detail and has given tabular analyses, soil profiles, pH determinations, and measurements of organic content of selected patches.

In Böcher's (1954) study of the plant communities in southwest Greenland, the vegetation is divided phytogeographically on the basis of the distribution of the species, especially their climatic and soil preferences. Two main vegetational areas: oceanic and continental are described. Each area is subdivided into vegetation complexes which have a homogeneous ecology, and again into vegetation types which are of homogeneous appearance.

Further vegetational descriptions and ecological data are in preparation by K. Holmen from Peary Land, by H. Mathiesen from northeast Greenland, and by K. Jakobsen from northwest Greenland. Investigations of plant communities dominated by lichen or by moss are being made by Skytte Christiansen and K. Holmen respectively.

In 1948 S. Nielsen began a quantitative study of the phytoplankton of Disko Bugt. His results will be published with other recent analyses using radioactive carbon (C-14) to study the organic production. N. Foged's paper on the west Greenland diatoms (1953) contains abundant ecological data including halobion and pH spectra for the waters investigated.

Tree planting

In 1948 C. A. Jørgensen and the late C. H. Bornebusch studied the present tree growth and the possibilities for future planting in southwestern Greenland. Since then, in collaboration with Syrach Larsen, Jørgensen has grown a large stock of young trees in Denmark of various forest species which should be suitable for Greenlandic conditions. Under Jørgensen's supervision these trees have been planted out in the most sheltered valleys of south Grenland, and a tree nursery has been established at Uperniviarssuq near Julianehaab.

Future work

The most immediate need is for investigations of the botanically least known regions of Greenland by qualified botanists. Districts which should be visited as soon as possible include the areas between Peary Land and the Thule district, between Danmarks Fjord and Skærfjorden, and parts of southeast Greenland. Reinvestigation of the inner Scoresby Sund area is also needed as the ecological conditions seem to be especially interesting, and there are possibilities of finding isolated occurrences of continental Siberian or North American species. Finally, the great amount of botanical work which has been done in Greenland should be crowned with the publication of a complete and scientific Greenland flora, including vascular plants, mosses, and thallophytes. Such a work would be an important milestone in Greenland research, and would be invaluable for future investigations of the country.

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II. Zoology and Marine Biology. By M. J. Dunbar[1]

Terrestrial and freshwater faunistic studies

The "Zoogeographical investigation of Greenland", organized under the Greenland Department of the Danish Ministry of State, and with the cooperation of the Zoological Museum of Copenhagen University, began field work in 1948, and has as its final objective the complete exploration and classification of the land and freshwater fauna of Greenland from the zoogeographical point of view. The investigation is carried out by Christian Vibe with the assistance, in the field, of young Greenlanders who show special interest in natural history.

During the six years 1947 to 1952, Vibe covered most of west Greenland in this way, from Thule to the Julianehaab district. In the 1953 season he worked from Mesters Vig on the east coast along the shores of Kong Oscars Fjord. All land animals and all freshwater animals are collected, and the insects, which are being worked up for publication, have so far yielded over 100 species new for Greenland and over 30 new to science.

This study of the Greenland fauna, and especially of the insects and mammals, has given support to the view that there must have been an ice-free area in the north of Greenland during the Pleistocene glaciation, which served as a refuge for much of today's "high-arctic" fauna in north Greenland as a whole. It also supports the theory, first put forward by Murray (1912) and by O. Pettersson (1913), that the glaciation caused the Polar Basin and surrounding land areas to be isolated more or less completely from what we know today as subarctic and boreal regions, even to the extent of containing, to a large degree, the polar water, and preventing the Atlantic Drift from affecting the climate of the polar regions. Thus the southern part of Greenland, on this view, might have been milder than it is at present, owing to the blocking of the Atlantic water south of the barrier. The barrier is taken to have been along the Wyville Thompson ridge and its extension westward to Greenland.

The present-day fauna is divided into a northern "high-arctic" and a southern "low-arctic" element, the former restricted to the extreme northwest, the north, and the northeast, and the one sharply separated from the other by the conditions of winter climate. In the high-arctic climate the mean summer temperature is below 6°C, and the winter temperature is always

[1]Text completed in 1953.

below freezing, never showing the sharp oscillations of freeze and thaw which are so common in the low-arctic winter. The high-arctic fauna, including (among the mammals) muskox, caribou, Greenland lemming, weasel, arctic hare, and fox, is circumpolar in distribution. In low-arctic areas the caribou and hare tend to be restricted to high altitudes, and the fox to the tidal zone, in feeding habits, and they differ racially from their counterparts farther north.

The low-arctic insect fauna of Greenland contains a large number of boreal species, partly nearctic, partly palearctic, partly holarctic, and partly confined to Greenland. They are taken to be the remainder of an originally much richer boreal fauna which in Europe and North America was in part extinguished during the glaciation or has since succumbed in competition with immigrants. Scattered occurrences of this fauna are to be found on both coasts of Greenland up to the 72nd parallel.

Vibe has also undertaken a biometric study of the Greenland fox material collected in recent years and to be found in the collection of the Zoological Museum in Copenhagen, which has resulted in the conclusion that not less than three distinguishable races exist in Greenland: one in the extreme northeast, in common with the Canadian Arctic Archipelago, one with a discontinuous distribution in northwest and east Greenland, and one in the southwest.

Marine and terrestrial zoology in Peary Land and the northeast

The zoologist on the Danish Pearyland expedition, Palle Johnsen, made collections of both land and marine animals, to be worked up and published in due course; and our knowledge of the biology of the plankton and other marine fauna in pure polar water should be further advanced by the sending of a young biologist to Danmarks Fjord in 1953, on the northeastern corner of Greenland, to make a year's study of the biological cycle in the sea. The results of this study should be extremely interesting, for it will shed light on the still obscure problem of the production level of life in the polar sea itself, and allow direct year-round observation of the growth rates of planktonic forms in that very cold water.

Fisheries and marine biological investigations in west Greenland

These are the largest-scale biological researches in Greenland, and have been so for a long time, for the good reason that the marine resources of Greenland are by far the most important to the country's economy. They began, in the present organization, in 1908, under A. S. Jensen, and have now for many years been led by Poul M. Hansen. The investigations expanded greatly when it became clear that the increased Atlantic influence in the west Greenland waters, first observed about 1917–20, was to endure for some time, and that therefore the cod and halibut fisheries, especially the former, would reach first-rank importance if properly developed. A new research vessel, the 38-ton *Adolf Jensen,* was brought into use after the last war, and several motor boats are also engaged in the field work.

Much of this work is continued routine, involving the recording of the size and age of the fish taken each year, and of their migration. Current developments, and future plans, may be summarized under the following headings:

Cod: Particular attention is being paid at present to the stocks of Atlantic cod (*Gadus callarias*) in Godthaab and Ameralik fjords. These fjords lie side by side but are of quite different kind: Godthaab Fjord is a so-called "Atlantic" fjord, with a deep or much indented threshold allowing the passage of Atlantic water at all depths, and Ameralik Fjord is an "arctic" fjord with a high submarine threshold which keeps out the deeper water and therefore builds up in the deeper parts of the fjord a local water-mass of low temperature, below zero Centigrade. The cod in the two fjords are of similar year-class composition and otolith type, different in both characteristics from the rest of the west Greenland stock, but the Ameralik population does not stay in the fjord all the year round. It moves out with the caplin (*Mallotus villosus*)—an important food organism of the cod—in the summer. The Godthaab Fjord stock remains in the fjord the whole year and has a slower growth rate than the Ameralik cod. The Godthaab cod are extremely numerous, and their smaller size is no doubt mainly due to overcrowding. It is thought that the Ameralik cod are the surplus of the Godthaab stock.

Three recent observations on the west Greenland cod, published in Hansen's report on fishery research for 1952, are interesting and so far largely unexplained: (1) The largest cod and the older year-classes are found in the northern part of the west Greenland waters (Disko Bugt and northward). (2) The average length of the cod taken in the commercial catch in 1952, year-class for year-class, was significantly lower than during the years 1931–9. The cause of the decrease in growth-rate is probably a food shortage brought about either by overcrowding or by a change in the hydrographic conditions. (3) Marking experiments have shown an emphatic movement southward along the coast of fish which grew up in the north. This is apparently a new development and somewhat mystifying, particularly since the northern waters have hitherto, at least in recent years, shown as good or better conditions for the growth of the cod, when compared with the southern part of the coast. There is naturally an anxiety, fostered also by short cold reversions in the climate during the past few years, that this phenomenon may have some connection with a weakening of the influence of the Atlantic water.

Other fishes: The Atlantic halibut, the arctic halibut, Greenland shark, arctic char, herring, redfish, catfish, and lampsucker are all used to a greater or lesser extent commercially or for local consumption. Recently Jørgen Nielsen joined the staff of the Greenland Fishery Investigations to work on the arctic char and the herring.

The Greenland shark, *Somniosus microcephalus*, has been fished in Greenland since the beginning of the nineteenth century, the oldest fishery in the country. Dr. Hansen has recently reviewed the fishery and what little is known of the biology of this remarkable fish in an article (1953) in the new

journal *Grønland*, published in Copenhagen. It is essentially an arctic rather than a subarctic fish, although found also in the Subarctic, and it is becoming less abundant in west Greenland, especially in the southwest, as a result of the warming of the marine climate in recent decades. It is still important north of Disko Bugt, and it is probable that the population has increased on the Canadian side of Baffin Bay owing to this northward movement into water of more arctic origin; but since the Canadian Eskimo have never used the shark, this must remain conjecture for the time being. It is an interesting and unexplained fact that the vitamin A content of the liver oil of the Greenland shark is always higher in arctic water; higher in east Greenland than in west Greenland, and higher in the northern part of west Greenland than in the southwest.

The value of the shark is not inconsiderable. In 1948 it was worth a little over one million kroner (Danish) to the Greenland economy, and the value of the Norwegian shark fishery in east Greenland was five times as great. The Norwegian shark fishery is pursued mainly in the Denmark Strait area, where it is now more important to the Norwegians than the hooded seal hunt.

Shrimp: The deep-water shrimp, *Pandalus borealis*, is growing in economic importance in Greenland; new trawling grounds have been found, and a new cannery has been built at Narssaq in the Julianehaab district. Erik Smidt is engaged in a study of the biology of the shrimp in Greenland, and has taken a leading part in the exploration for new grounds. In 1951 trawling experiments in Godthaab Fjord gave poor results in the Kugssuk channel and at Korkut; trawling in the Kapisigdlit area was more successful, but the production was nevertheless not large. Farther south, Kvanefjord gave poor results, but the experiments at Ivigtut were very successful, and the middle and outer parts of Igaliko Fjord also gave good results. These will give useful support to the new cannery at Narssaq, which is already being supplied from the trawling grounds in Skovfjord, Tunugdliarfik Fjord, and Lichtenaufjord, discovered some years earlier.

The shrimp stocks in the Holsteinsborg district were badly damaged by the low temperatures of the 1948–9 winter. Temperatures at the bottom of Amerdlok and Ikertok fjords dropped from about 1.5°C in the summer of 1948 to -1.5°C or lower in the summer of 1949. The temperatures are now back to the 1948 level, but the shrimp stocks are still small. The shrimp supplied to the Holsteinsborg cannery in 1949–50, a record year, came from new trawling grounds in Disko Bugt.

Zooplankton work at Narssaq: A student, Svend Haasted, went to Narssaq on a year's study of the biology of the Greenland shrimp in 1953, particularly to examine the planktonic stages, and the zooplankton in general. He planned to take regular quantitative samples of the plankton with Hensen nets in different depth ranges during a full twelve-month cycle; this will provide material for the study of the whole annual production cycle of the zooplankton in a subarctic area with ice-free water during the winter.

Marine biological station at Godthaab: The scientific station at Godhavn, established early in the present century by Morten P. Porsild, is well known. It has recently been taken over by Copenhagen University. The marine biological station at Godthaab, on the other hand, is quite new (1953), and is run by the Greenland Fishery Investigations under Dr. Hansen. In charge of it is Jens Kreutzmann, a young Greenlander who became interested in marine biology while still at school at Godthaab during the war (with the practical encouragement of the Canadian Consulate), and became assistant on board the research ship *Adolf Jensen* and at the Copenhagen headquarters, in the following years. The station will be occupied in the collection of information on fish and seal from the Greenland fishermen and hunters, and in the biological investigation of Godthaab and Ameralik fjords. From the marine biological point of view, it is ideally situated. Kreutzmann will also make quantitative routine plankton collections all year round at four stations in Godthaab Fjord and the surrounding waters, including phytoplankton samples taken with the Nansen bottle.

Seal: Marine research in Greenland has not hitherto paid much attention to the sea mammals. But the possibility of a return to colder marine conditions, which would increase the economic importance of the mammals at the expense of the fishes, and the general interest expressed internationally in such organizations as the International Committee for the Northwest Atlantic Fisheries (ICNAF), have directed the attention of the Danes to research on these animals in Greenland. Field research on marine mammals is not easy except at the breeding grounds, but it is planned to carry out investigations of census, migrations, and age composition on the seals of west Greenland, in cooperation with the Norwegian work in east Greenland and the Canadian investigations on the harp seals (*Phoca groenlandica*) in the waters of Newfoundland and the Gulf of St. Lawrence, and the ringed (*Phoca hispida*) and bearded seals (*Erignathus barbatus*), and walrus (*Odobenus*) in the Canadian Eastern Arctic.

Offshore research west of Greenland

All the marine work summarized above, except in Peary Land and Danmarks Fjord, comes within the operations of the Greenland Fisheries Investigations headed by Poul M. Hansen, and under the aegis of the Greenland Department. In the offshore waters of west Greenland, and also east of Greenland, hydrographic and biological work, with emphasis on the former, has been done and is being done by the staff of the Danish Fisheries and Marine Research Laboratory on board the Research Vessel *Dana*, and also by the Norwegians. The stations occupied by the *Dana* in 1950 and 1952, and by the Norwegian ship *Uran* in 1948, are shown in Fig. 1. The *Dana* sections are now routine, and most or all of them will be maintained every year in future. In 1953 the southernmost section southwest from Kap Farvel was extended as far as the Labrador coast. The usual physical and chemical parameters are measured at these stations, samples for the determination of the phytoplankton crop are taken, and mid-water trawls with such nets as

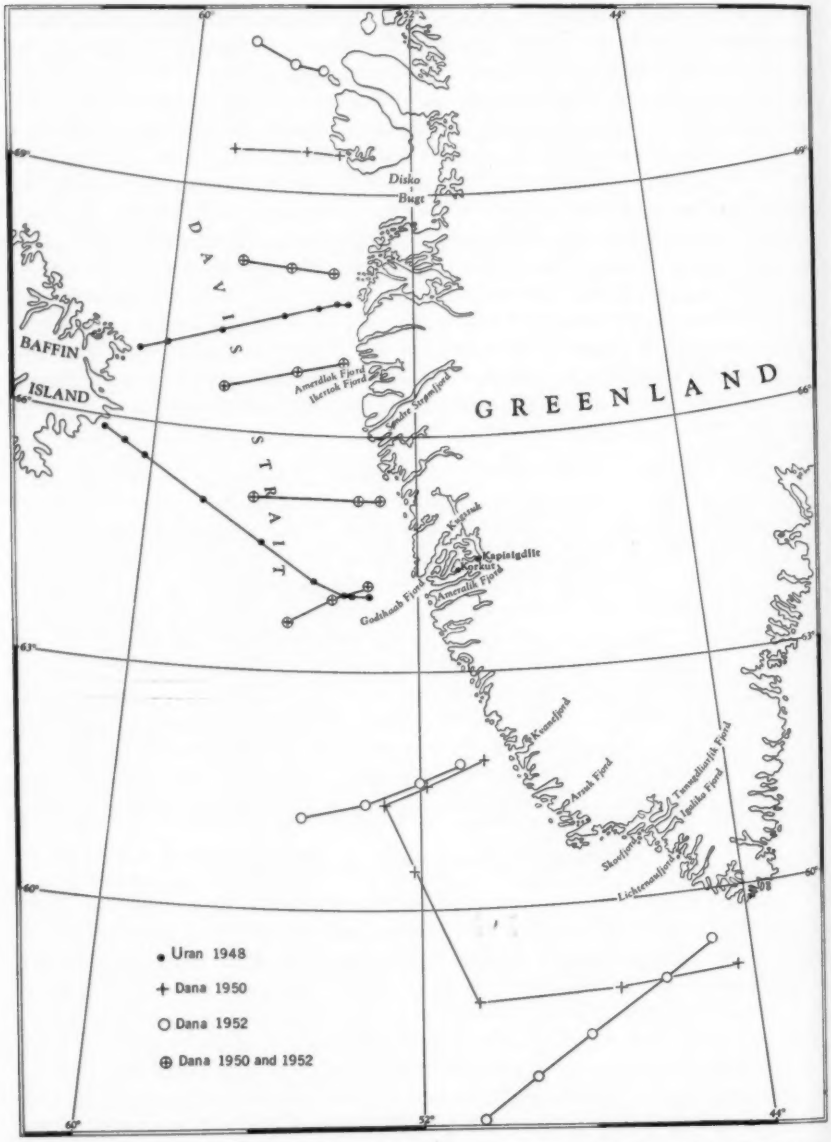

Fig. 1. Hydrographic and plankton stations in waters west of Greenland in 1948, 1950, and 1952. (From a drawing prepared by J. Grøntved).

the 2-metre stramin trawl are made. The value of this work can hardly be over-estimated, because it provides an annual record of hydrographic and biological conditions in an oceanographic region which is, at the present

stage in the postglacial cycle, peculiarly subject to oscillations, and which at the same time is of very great economic importance to man; and the economic importance depends on the climatic cycle to a great extent.

Fundamental to the economic value of the Canadian Eastern Arctic and west Greenland are the factors underlying the differences in, and variations in, organic production in the sea. Studies of the rate of production of organic material in the west Greenland waters have begun, and in the meantime the estimation of the standing crop of phytoplankton during the summer months is receiving special attention on the basis of samples collected by the *Dana*, the *Uran*, and the *Adolf Jensen*, which are being worked out by Julius Grøntved in the Plankton Laboratory at Charlottenlund Slot in Denmark. Quantitative phytoplankton investigations on the west Greenland banks were first made by the Norwegian biologist Gran (1929), and a recent manuscript report by R. W. Holmes deals with the annual cycle of the phytoplankton in the Labrador Sea (1950–1) based on weekly collections made on board the weather ship at Station Baker (56°30N., 51°00W.) Grøntved's work, however, which will be published in the *Meddelelser fra Danmarks Fiskeri- og Havundersøgelser*, will be of much greater scope than either of these studies, based as it is on quantitative collections during three seasons at the stations shown in Fig. 1, plus stations occupied by the *Adolf Jensen* in April and May 1950 and 1952 on the Fylla and Store Hellefiske banks.

In the preparation of this paper the writer was indebted to Dr. Poul M. Hansen, Magister Julius Grøntved, Dr. Erik Smidt, and Magister Christian Vibe for material on the work in which each is engaged, and in particular to Magister Grøntved for the map of the sections given in Fig. 1.

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ARCHAEOLOGICAL RESEARCH IN THE NORTH AMERICAN ARCTIC

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If anthropological research in the Arctic is to achieve its broadest aims it must be concerned with such basic problems as when, where, and under what circumstances man first penetrated the far north; the ecological conditions encountered during his occupancy of the region; the mechanical, economic, and social adaptations that enabled the Eskimo, the most typical of the arctic peoples, to devise a pattern of life uniquely suited to arctic conditions; the physical and cultural relationships between the Eskimo and other peoples, and how and why their culture changed in the course of time. The practical approach to these underlying problems is through archaeology – the discovery and excavation of early Eskimo or pre-Eskimo sites which will show us how these people lived in the past. In the following summary I will discuss briefly the current status of arctic archaeology, pointing to present accomplishments and further problems toward which research should be directed.

The first systematic archaeological work in the Arctic was that of Mathiassen (1927) who excavated at old Eskimo village sites north and west of Hudson Bay in 1922–3. The result was the discovery of the prehistoric Thule culture, which was closer to that of Alaska and Greenland than it was to the culture of the present-day Central Eskimo. Mathiassen therefore concluded that the Thule people had come originally from the west, either from Siberia or Alaska, and moved into the Central Arctic around 1,000 years ago. In 1925 Jenness (1925) described another prehistoric Eskimo culture, the Dorset, which was older than and very different from the Thule. Centering around Hudson Strait, the Dorset culture extended south to Newfoundland and north to northwestern Greenland.

The first excavations in the Western Arctic were made in 1912 by Stefansson, who worked at Birnirk, an old site near Point Barrow (Stefansson, 1914). Later evidence indicates that the Birnirk was the Alaskan stage of culture ancestral to Thule (Collins, 1940). Jenness' excavations in 1926 at Cape Prince of Wales and Little Diomede Island in Bering Strait brought to light the first traces of the Old Bering Sea culture, and marked a turning point in Eskimo archaeology (Jenness, 1928 a,b, 1933). With an estimated age of around 2,000 years, the Old Bering Sea was the earliest Eskimo culture known from the Western Arctic. However, it was already a highly developed and specialized Eskimo culture, richer in many ways than that of the modern

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Eskimo, especially in its elaborate and sophisticated art style. Later investigations on St. Lawrence Island brought full information on the Old Bering Sea culture, and on an intermediate phase, the Punuk, which was contemporaneous with the Canadian Thule culture (Collins, 1929, 1935, 1937; Geist and Rainey, 1936; Rainey, 1941). The results of the St. Lawrence investigations, like those of Mathiassen in the Central Arctic, pointed strongly to the conclusion that Eskimo culture was a product of the Old World, for the basic features of the Old Bering Sea culture were much more Asiatic, or Eurasiatic, than American (Jenness, 1933, 1941; Collins, 1937, 1940).

De Laguna's excavations at Cook Inlet (1934), those of Hrdlicka (1944) on Kodiak Island, of Weyer (1930) on the Alaska Peninsula, and of Jochelson (1925), Hrdlicka (1945), Laughlin (1951, 1952 a,b), Spaulding (1953), and Bank (1953) in the Aleutians, have brought valuable information on prehistoric culture development in the southernmost part of the Eskimo territory. The earliest stages of culture in south Alaska were more Eskimoid than the later, when Indian influences began to be felt. Comparisons with northern Alaska indicated that the south Alaskan culture was basically Eskimo and that its carriers had left the Bering Strait region before the time of the Old Bering Sea culture, a deduction that is borne out by radiocarbon dates of $3{,}018 \pm 230$ years for early Aleutian and $2{,}258 \pm 230$ years for early Old Bering Sea (Okvik).

The Ipiutak culture discovered at Point Hope on the arctic coast of Alaska by Rainey, Larsen, and Giddings in 1939 is of particular importance because of its spectacular character and the far-reaching theories that have been built around it (Larsen and Rainey, 1948). In art style and many of its implement types Ipiutak closely resembled Old Bering Sea, especially the earliest phase of that culture, the Okvik. In other respects it was very different from Old Bering Sea or any other Eskimo culture. It lacked such typical Eskimo features as lamps, pottery, sleds, the bow drill, and rubbed slate blades, and possessed many curious ivory carvings, which were placed with the dead as burial offerings. Blades for tools and weapons were all of chipped stone, and some of the forms closely resembled those found at early Neolithic sites in Siberia. The Ipiutak people knew the use of iron, and this, together with the fact that some of their animal carvings and religious and ceremonial practices were strongly reminiscent of the Siberian bronze and iron ages, led Larsen and Rainey to suggest that the Ipiutak people had lived originally along the lower Ob' and Yenisey rivers and that they had migrated to Alaska around the first or second centuries A.D. On the other hand, the Ipiutak culture was also thought to have been basically related to that of inland Eskimo peoples such as the Caribou Eskimo west of Hudson Bay and the Nunatagmiut of interior Alaska, as well as to the prehistoric Dorset, Kachemak Bay, and Aleutian cultures. Ipiutak was thought to represent the type culture of a Palae-Eskimo complex from which all other Eskimo cultures had been derived. Some of the basic assumptions of this new theory of the origin of Eskimo culture have been questioned by Collins (1951, 1954 a,b) who, in the meanwhile (1943) had advanced the

theory that Eskimo culture was of Mesolithic origin, because of resemblances between the earliest Eskimo cultures in Alaska, the early Siberian Neolithic, and the Mesolithic of northern Europe.

Giddings (1949, 1951) at Cape Denbigh and Larsen (1950) at Kuskokwim Bay have excavated sites with Ipiutak-like culture (but containing lamps, pottery, the bow drill, and rubbed slate implements), indicating that the culture of the Alaskan Eskimo of the Bering Sea coast region rested at least in part on an Ipiutak foundation, as postulated by Larsen and Rainey (1948). Or more properly it might be said, on an "Ipiutak-like" foundation, for it seems likely that the more widespread Ipiutak-like culture was the base from which the more localized Ipiutak culture proper developed.

The oldest cultural remains thus far found in the Eskimo territory are those of the Denbigh Flint Complex, discovered by Giddings in 1948 at Cape Denbigh on Norton Sound. It was found at the base of a stratified site beneath accumulations of Ipiutak-like (Iyatayet A, A^1 in Table 1) and later Eskimo material. The Denbigh Flint Complex is characterized by thin lamellar flakes and the flint cores from which they were struck, small finely chipped blades made from such flakes, a few Yuma- and Folsom-like blades, and several types of burins–specialized bone-grooving tools characteristic of the Upper Paleolithic and Mesolithic of the Old World, but not previously known from America (Giddings 1949, 1951). Material similar to that from Cape Denbigh has also been found at several sites near Anaktuvuk Pass in the Brooks Range in the interior of northern Alaska (Solecki, 1951; Solecki and Hackman 1951; Irving 1951, 1953), and some of the Denbigh implement types have been found at other inland locations: Fairbanks (Nelson, 1937; Rainey, 1939), the lower Tanana River (Rainey, 1939), Kluane Lake (Johnson, 1946), and the Mackenzie River drainage (MacNeish, 1954).

The presence of a few fluted points and Yuma-like blades at Cape Denbigh and geological indications that the site might be of considerable antiquity (Hopkins and Giddings, 1953) have sometimes been interpreted as indicating a relationship between the Denbigh Complex and the Paleo-Indian or Early Man complexes of western North America. However, the Yuma- and Folsom-like blades at Denbigh may be relics of an earlier period, and not evidence of a direct relationship with Paleo-Indian (Wormington, 1953; Collins, 1953 a,b). Consistent with this view is the discovery by MacNeish (1954) of Paleo-Indian type material (Sandy Lake) underlying microlithic Denbigh-like material (Pointed Mountain) near Fort Liard, N.W.T.

On the other hand, there are indications of a cultural connection, despite a great time gap, between the Denbigh Flint Complex, pre-Dorset and Dorset-like cultures in Canada and Greenland, and the typical Dorset cultures of these regions (Collins, 1951, 1953 a,b, 1954a; Knuth, 1952; Meldgaard, 1952; Harp, 1953). There are also significant resemblances between some of the Denbigh implements and those of the much later Ipiutak culture (Giddings, 1951; Collins, 1951, 1953b, 1954a; Harp, 1953). It appears, therefore, that the Denbigh Flint Complex was one of the sources, perhaps the principal source, from which Eskimo culture developed. Though the Denbigh Complex and

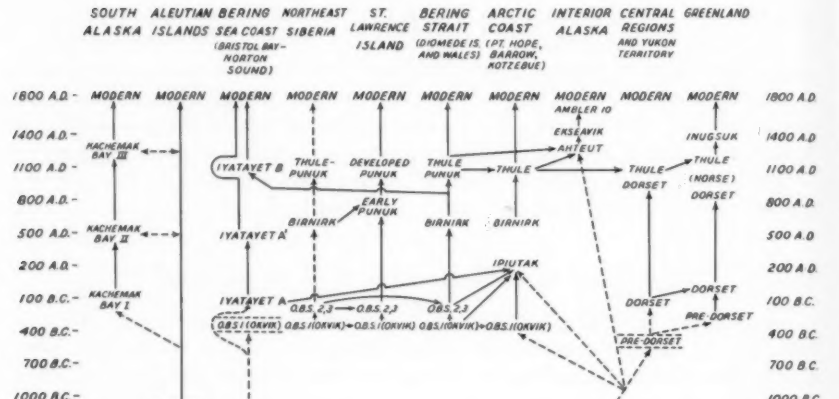
later culture stages related to it seem to have extended from Bering Sea to Greenland, it was not entirely, or perhaps even primarily an American phenomenon. Recent reports by Russian archaeologists have described Mesolithic sites in Siberia containing burins, lamellar flakes, and other stone implements like those found at Denbigh. These Siberian sites do not stand in isolation; rather, they are part of the Eurasiatic Upper Paleolithic–Mesolithic continuum. This suggests that the pre-Eskimo Denbigh Flint Complex as known in Alaska may eventually be revealed as an easterly extension, on American soil, of a widespread Eurasiatic culture of Mesolithic age from which the earliest forms of Eskimo culture were derived.

Problems and research needs in Archaeology

In Alaska the principal tasks for archaeology may be summarized as follows: (1) Discovery and investigation of early pre-Eskimo sites on the coasts and in the interior to determine the relationship between the Denbigh Flint Complex and related culture phases on the one hand and the formative stages of Eskimo culture and early Indian manifestations on the other; (2) the delineation of inland patterns of prehistoric Eskimo culture, only one of which, that on the Kobuk River, is thus far known (Giddings, 1952); (3) additional excavations to determine the interrelationship that existed between the three principal early Eskimo culture patterns in Alaska, (a) the Aleutian and south Alaskan culture, extending in a variety of local forms from Prince William Sound to Bristol Bay, (b) the Old Bering Sea culture, known in its most fully developed form on the Siberian coast of Bering Strait and on St. Lawrence Island and the Diomede Islands, and in its Okvik phase also on the north coast of Alaska and possibly at Kuskokwim Bay, and (c) the Ipiutak culture, known from Point Hope, Kotzebue, and Seward Peninsula, and in related form on the Bering Sea coast from Norton Sound to the Kuskokwim.

The nature of the archaeological problems is illustrated to some extent by Table 1, which attempts to place known and postulated culture stages in chronological order and to trace lines of continuity and development. Solid lines and directional arrows indicate cultural relationships and sequences for which there is archaeological evidence, broken lines hypothetical movements and sequences which appear probable but for which direct evidence is lacking. Broken lines are also used to indicate hypothetical culture stages. The chronological positions of Chaluka on Umnak Island, Old Bering Sea 1 (Okvik), and Iyatayet A, A^1, and B are based on radiocarbon dating, and Ahteut, Ekseavik, and Ambler Island on dendrochronology. The names Iyatayet A and A^1 are used here, for convenience, to designate Giddings' "middle levels" of Ipiutak-like or Palae-Eskimo culture at the Cape Denbigh site; Iyatayet B is the "Neo-Eskimo" layer containing Punuk type material at the same site. O.B.S. stands for Old Bering Sea, and the numerals 1, 2, and 3 for its stages, based mainly on art styles. Ipiutak, because of its close resemblance to Old Bering Sea, is placed around A.D. 300 rather than A.D. 1,000, its radiocarbon date.

Table 1. Known and postulated culture stages



In approaching these problems, in Alaska or other arctic areas, close attention should be given to the environmental background, past and present, with a view to tracing possible changes in culture and ecology correlated with climatic fluctuations which have occurred during the period of human occupation. This calls for the preservation and study of all faunal remains: the number and relative abundance of different species of mammals, birds, fish, and molluscs at neighbouring sites or at different levels of the same site; the state of preservation and patination of such animal remains and the associated bone and ivory artifacts, and whether or not this is correlated with the presence or absence of permafrost; indications of former absence of permafrost (organic materials absent or poorly preserved) at sites now frozen; comparison of earlier faunal assemblages and those of today; the location of old sites in relation to present and older shore lines and terraces; presence of old sod lines and the nature of the soil, sod, and the plant cover at sites of different age; state of preservation of house ruins, their external appearance, degree of fill, depth of sod, and nature of surface vegetation; collection of soil, sod, bone, wood, charcoal, and other organic materials for pollen, chemical, and radiocarbon analyses.

Excavations almost anywhere in Alaska where old sites exist may be expected to contribute to solution of the problems. In the Aleutian Islands, for example, where there seems to have been considerable cultural variation

from island to island, there is need for additional local chronologies to illustrate growth sequences in different parts of the archipelago, and for comparison between these and culture sequences elsewhere, particularly Prince William Sound, Cook Inlet, Kodiak, the Alaska Peninsula, and the Bristol Bay–Kuskokwim area. The Aleut practice of burying their dead in village refuse heaps presents an unusual opportunity to correlate physical type with culture change. The early Aleuts were longer headed than the modern, though the early type has persisted in the more westerly islands (Laughlin, 1952b; Laughlin and Marsh, 1951). It would be interesting to know whether cultural changes in the eastern part of the Aleutians coincided with the appearance of a different physical type, the very broad and low-headed modern Aleut. We should not assume, however, that cultural impulses moved only *into* the Aleutians. The fact that Aleutian culture, on the basis of radiocarbon dating, is older than any other known form of Eskimo culture and that these islands supported a denser population than any other part of the Eskimo territory, would suggest that cultural influences had emanated from there to the mainland. To cite one possibility: the art of the modern Eskimo in the Yukon–Bristol Bay area is very much like the prehistoric Punuk art of St. Lawrence Island, and Punuk elements such as nucleated circles also occur in the Aleutians and Cook Inlet. The writer has interpreted this as indicating a southward diffusion of Punuk art from Bering Strait. However, these design elements might prove to be older in the Aleutians and on the Bering Sea coast than around Bering Strait, in which case the opposite explanation would be in order, an explanation which, by the way, would harmonize with the sudden appearance of the southwestern Eskimo type of house on St. Lawrence Island during the Punuk stage.

The Bering Sea coastal region, lying as it does between Bering Strait and the Aleutians–two centres of high but dissimilar cultural development–has long been recognized as archaeologically important, but until recently, except for Weyer's (1930) excavations at Port Moller on the Alaska Peninsula, it had remained a complete blank. Giddings' (1949, 1951) and Larsen's (1950) excavations at Norton Sound and Kuskokwim Bay, respectively, have revealed culture sequences in these localities, and information on the latter phases of prehistoric culture at Hooper Bay and Nunivak Island has been presented by Oswalt (1952) and VanStone (1954). The culture of the modern Bering Sea Eskimo seems to have developed from a foundation of Ipiutak-like culture (Iyatayet A, A^1 in Table 1) to which Punuk elements may have been added.

There is need for more precise information on the nature of the relationship between Old Bering Sea 1 (Okvik) and Ipiutak and related culture stages. Ipiutak proper (Point Hope) is closely connected with Okvik, and Okvik art is present at other sites of Ipiutak-like culture at Kotzebue Sound and Seward Peninsula (Larsen, 1951). A single example of typical Okvik art from an old site on Kuskokwim Bay, collected by E. W. Nelson in 1879 (Collins, 1940, p. 575), suggests the possibility that Okvik art may have formed part of the Ipiutak-like culture discovered by Larsen (1950) in the same region. If so, it might mean that Okvik, related to the widely distributed Ipiutak-like

culture, had originated in Alaska rather than Siberia, where it is known thus far only at old sites on the western side of Bering Strait. Excavations at additional sites in southwest Alaska, if possible at stratified sites, should elucidate this problem and provide the needed cultural chronology for the region.

Equally important would be excavations at old sites on the Yukon, Kuskokwim, Togiak, and Nushagak rivers, and on Wood River and the chain of lakes to the north, to observe the pattern of culture change produced by the transition from a coast to inland environment. The only intensive excavations of inland Alaskan sites are those made by Giddings (1952) on the Kobuk. These sites—Ahteut, Ekseavik, Old and Intermediate Kotzebue, and Ambler Island—are dated by dendrochronology and are all relatively recent, from A.D. 1250 to 1760. In Giddings' opinion the Kobuk sites are representative of an "Arctic Woodland Culture", an inland-coastal manifestation distinct from Eskimo. It should be noted, however, that the harpoon heads from the oldest Kobuk site—Ahteut, 100 miles inland from the sea—are identical in every respect with Punuk heads from St. Lawrence Island. Moreover there is close similarity, or identity, between most of the other Kobuk implements and those from coastal Eskimo sites of comparable age. This would suggest that the Kobuk culture was an inland extension of coastal Eskimo.

Giddings' Kobuk chronology should be extended by the excavation of older inland sites in an attempt to bridge the enormous time gap between Ahteut and Anaktuvuk and other pre-Eskimo inland manifestations related to the Denbigh Flint Complex. Such excavations might provide an answer to the much discussed question of inland versus coastal Eskimo origins. How many, if any, of the hundreds of old sites in the interior of Alaska—now known mainly from small surface collections of artifacts—are those of true inlanders, people who had no connection whatever with the sea? The dialect of the one remaining group of inland Eskimo, the Nunamiut of the Anaktuvuk Pass region, differs very little from that spoken on the arctic coast, and we know that the inland people in general maintained close trade relations with the coastal people, on whom they depended for seal oil, hides, and other necessities. The linguistic and other evidence would seem to indicate that the Eskimo who lived along the Colville and other rivers in the interior of Alaska in historic times were the descendants of coastal Eskimo who had moved inland to establish an economy based on caribou hunting and fishing rather than the pursuit of sea mammals. There may have been earlier inland peoples whose culture did not conform to this pattern, but this needs to be proved before assuming the existence of an inland form of Eskimo culture unrelated to that of the coasts. In this connection it should be recalled that the earliest cultural manifestation known from the Eskimo area, that of the Denbigh Flint Complex on the Bering Sea coast, had inland parallels at such sites as Anaktuvuk, Howard Pass, and Pointed Mountain.

Larsen and Rainey (1948) have assumed a dual origin for Ipiutak—an original inland base on which coastal features were superimposed. Though other facets of the Ipiutak theory seem dubious at best, the Ipiutak stone industry from all indications was related to that of the Denbigh Flint Complex,

and the intermediate stages from which this lithic component was derived may well have been inland. This is indicated in Table 1 by a broken line leading from a postulated Denbigh-derived inland culture to Ipiutak. A similar line leads to Ahteut, the oldest of the Kobuk sites, and the assumption here is the same, namely that its flint industry, and perhaps that of the arctic coast Eskimo in general, was derived mainly from inland sources.

In arctic Canada and Greenland the principal problems are those of the Thule, Dorset, and pre-Dorset cultures. In the Canadian Arctic Archipelago Thule sites have been found containing material identical with that from Alaska and the earliest Thule sites in northwest Greenland (Holtved, 1944; Collins, 1950, 1952). This would indicate that the first Thule migrants from Alaska took the far northern route, through the tier of islands north of Melville and Lancaster sounds, rather than through territory adjacent to Hudson Bay. Return movements of Thule peoples to Alaska within the past few centuries may also have followed this northern route. Additional excavations are needed to show the relationship between this northern phase of the Canadian Thule culture and that to the south which has been more strongly influenced by Central Eskimo culture.

The basic problem in the archaeology of the Central and Eastern Arctic is that of the Dorset culture and its antecedent stages. The widespread occurrence of the Thule culture in arctic Canada and Greenland, the impressive appearance of its stone and whalebone house ruins and the prevalent Tunit legends attached thereto, have emphasized the role of the Thule culture in the prehistory of the region. Dorset sites, though numerous, are much less conspicuous than those of the Thule culture. Lacking surface indications, such as the visible pits and fallen superstructures of old house ruins and the lush vegetation surrounding them, the older Dorset sites have often escaped the attention of the casual observer. The fact that they are so inconspicuous in appearance, with a plant cover differing little from that of the surrounding terrain, is in itself an indication of age, as is the further fact that Dorset material is frequently found underlying Thule house ruins or middens. Dorset sites are now known throughout the Eastern Canadian Arctic—from Newfoundland north through Baffin Island, along both sides of Hudson Bay, and on the eastern islands of the Arctic Archipelago—and in all parts of Greenland. The question is in what way and to what extent the Dorset culture may have contributed to the formation of present-day Eskimo culture of the Central regions and Greenland. We know that one important element—the dominant form of sealing harpoon head used by the Central and Greenland Eskimo—was derived from a Dorset prototype, and it is difficult to believe that this was an isolated phenomenon. Future research may be expected to reveal Dorset as the basic substratum of Eskimo culture in arctic Canada and Greenland.

Though the Dorset culture persisted into the Thule period in some parts of Canada, its roots extend much deeper. Indicative of its age is its marked variability, in contrast to the uniformity of the Thule culture remains found in the same areas. In the total range of implement types most Dorset sites differ considerably one from another, though a sufficient number of diagnostic

elements are present to distinguish all of them as belonging to a pattern which we can call Dorset. The picture that emerges is that of the rapid spread of a uniform Thule culture, which within the past 1,000 years or less was superimposed on the remnants of an ancient culture that had existed for many centuries in a variety of local forms in the same regions. Very few Dorset sites have been thoroughly explored, and because of our lack of knowledge the Dorset culture in many respects is still an enigma. There seems to be little doubt, however, as to its origin. Specialized types of implements such as burins, lamellar flakes, cores, and blades link the microlithic Dorset culture with the much more ancient microlithic Denbigh Flint Complex of Alaska. Intermediate in time between Denbigh and Dorset are several culture stages in Greenland (Knuth, 1954; Meldgaard, 1952) which in Table 1 I have listed provisionally under the general term "Pre-Dorset". The "Pre-Dorset" and earliest Dorset stages have been placed as late as 400 B.C. to A.D. 200 because of geological indications that the shores of Hudson Bay were subjected to marine submergence following the final ice withdrawal from around 1,000 to 500 B.C. The Hudson Bay littoral, where some of the Dorset and pre-Dorset sites are located, according to this theory could not have been occupied by man prior to 500 B.C. If this theory could be disproved and the time of the marine submergence pushed back a thousand years or more, the situation would be more in conformity with archaeological indications of a greater age for the Dorset and preceding culture stages in this region.

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PROBLEMS OF HUMAN ECOLOGY IN THE NORTH AMERICAN ARCTIC

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ALTHOUGH nearly everyone who has written about Eskimo culture has admired its specialized adaptation to the arctic environment, almost no one in recent years has studied in detail any ecological problem connected with the Eskimo, except in physiology and health. Since these two fields are outside the scope of this article, a survey of ecological research on Eskimo and white man's culture in the American Arctic could be made very quickly, but it is necessary to take account of all the bits of ecological information scattered through the literature before recommendations can be made for future work. Most of the relevant literature in anthropology, human geography, sociology, demography, archaeology, and biology, published since 1940, has been considered to ascertain the trend of recent research and the most serious gaps in our knowledge.

First, it is necessary to decide what adaptations have been made. Ideally, what a people started with in a given environment and the changes in that environment in the early stages of human occupation should be ascertained. The ecology of prehistoric man should be an important section of both archaeology and human ecology. Prehistorians of the Old World, dealing with long time-cycles, had to consider climatic changes, and prehistorians of the American southwest and western plains and plateau similarly assumed that early man had to deal with big changes in climate, flora, and fauna. Archaeologists of the American Arctic, however, did not relate the large postglacial changes to Eskimo development because they assumed that the Eskimo were more recent.

One of the principal effects of this assumption has been the further assumption that the climate has been as cold as or colder than now during the entire Eskimo occupation. (The increasing shallowness of the arctic seas was about the only recognized change). These assumptions would be acceptable if the Eskimo sojourn in the American Arctic had been only two thousand years, but if it were five thousand or more years old, a stable physical and biological environment could not be taken for granted. Fortunately, meteorology, glaciology, botany, and archaeology have advanced tremendously in knowledge and methods in the past fifteen years, so that prehistorians of

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the Arctic can get much assistance in ascertaining local climatic changes and their effects. Archaeologists now have little excuse for ignoring changes of environment through time.

The origin of the Eskimo, as well as their climatic environment, appears to have been oversimplified. The classic picture portrayed a people from central Siberia, central Canada, or northern Europe, developing and preserving a very specialized culture, then migrating in isolation, and meeting no one for generations. It was accepted that a few, rather superficial ideas later were imported from the eastern rim of Asia—lower Amur river, Japan, and the Kuril'skiye Ostrova—and a few more came still later from the Norse in Greenland. However, Eskimo history now appears to have been less simple. The culture developed different specializations in different places and at varying rates in different regions. There were diffusion of ideas and local adaptation as well as migration. It has now been recognized, if somewhat reluctantly, that Eskimo culture has had many variants.

Marsh and Laughlin, for instance, have recognized this fact for the "Aleut-Eskimo community" which Laughlin (1952, p. 36) has expressed as follows:

"Consideration of the variability in single material traits alone forces one to place more emphasis on the processes of innovation. The ground slate semi-lunar knife, common among the recent Aleuts and Eskimos, is confined to the later strata in the Aleutians. It was, however, preceded by a chipped semi-lunar knife which was, in turn, only one of several kinds of knives. If the single category of knives were considered for all past and present Aleut-Eskimo cultures, it would be apparent immediately that there has been considerable innovation. The number of such traits is so far in excess of the number uniformly found among all the peoples that neither diffusion from neighboring peoples nor migration of more distant peoples can be very useful in explaining their presence. One is perforce led to consider the processes of innovation. In view of the fact that innovation is known to have been specifically encouraged, this area of the culture must receive more thorough consideration before the 'sources' of Aleut-Eskimo culture can be exposed."

Even though Laughlin's emphasis on invention and local adaptation is justified, the possibility of migration of people to account for specific cultural resemblances across great areas cannot be rejected entirely. In 1941 Thalbitzer (1941, p. 635) published what seemed an extreme hypothesis:

". . . the Ammassalik culture reveals such a striking resemblance to the western Eskimo culture in certain localities even as far south as southern Alaska . . . that in some way or other there must be a definite connection. An explanation is needed. We might imagine the immigration of a special group from Alaska into Greenland, skirting the homogeneous Greenland culture known to us from other places, a wedge right through the Thule culture, ending on the east coast of Greenland."

If we could know more about the social structure, the ideology, and the personal and community ritual of Eskimo in intervening regions, such as Baffin Island and west Greenland, as they existed three hundred or five hundred years ago, we probably would find there, too, much of this Alaskan culture that Thalbitzer saw in east Greenland. Influence on the originally Alaskan Thule culture from the earlier Dorset people and later from Danes and other white men, also the influence of a worsening climate, induced the Thule people to change, and to relinquish much of their old way of life. Since there are

other good explanations, it is not necessary to postulate a small, rapid, wedge-like migration in order to account for similarities between Angmagssalik and Unalakleet. The movements, the patterns of change in one place and relative stability in another place, were more complex than a simple migration. Recently, however, Knuth's finding of an umiak, which is probably late Thule in date, in northeast Greenland gives new support to the theory of a migration around northern Greenland and down its east side (Knuth, 1952).

We have now reached a point at which it is wise to have no general theory. New archaeological finds are coming too fast, and it would be unsafe to assume, without really conclusive evidence, that there was or was not one long movement of Eskimo across the Arctic. At present we have greater need for hypotheses on specific local developments than for grand schemes to explain cultural resemblances between peoples far apart. To show that there are certain resemblances in technology and art is useful; to assert that one therefore has the same culture or the same period of prehistory could misdirect future research and explanation. We must especially avoid thinking in such general terms as Asiatic versus American or inland versus coastal origins.

There is also need for a certain amount of introspection on the nature of our thinking and theorizing on Eskimo culture. Scandinavian and British prehistorians of Europe and the Mediterranean world have developed a strong tradition of explaining cultural resemblances by migration, while American cultural anthropologists, in contrast, have as strongly emphasized diffusion from people to people. European and American archaeologists in the American Arctic have tended to follow the traditions of their respective scientific backgrounds. Neither group has relied on one kind of explanation exclusively, but the Danes have more frequently postulated migration, and the Americans have more frequently assumed diffusion among Eskimo and between Eskimo and other peoples.

Summarizing Eskimo ecology, Kroeber (1939, p. 22) made the following concise and penetrating comment:

> "What emerges from the total array of his [Steensby's] succinctly analyzed data is not the primacy or priority of one particular economic adaptation, but a picture of the totality of Eskimo culture as a unit, modified by emphasis or reduction of its traits in direct response to local exigencies. Here seals are the important food, there whales, or walrus, or caribou, or birds, or salmon, while others are as good as unavailable."

He could have added that where several of these animals are available, then all of them are hunted. What is remarkable about Eskimo is their versatility.

We still need to know not only that people do adapt but also the processes by which they do it. It is necessary, for this purpose, to study closely the recent past and the present, since for these periods we have information instead of speculation as to what the people started with on a given road of cultural change. Anthropology includes and requires both history and science. In addition to making studies of ancient arctic history, as such, Eskimologists can also contribute to science inductively derived principles of cultural adaptation. Many opportunities are open to those willing to undertake new lines of research. The following are some suggestions.

Population size and distribution

To obtain the data required for population problems a detailed study should be made of one area, for example, the Eskimo groups west of Hudson Bay. This study would be difficult, but most worthwhile. Genealogies for three generations back should be made for families in the region, or any part of it, from Chesterfield Inlet and Eskimo Point to Repulse Bay, Cambridge Bay, and Coppermine, and should indicate what groups the individuals came from. These data would be valuable to the physical anthropologist and public health worker as well as to the student of geographic mobility and group contact. There are already some data for part of this region and the coast farther west. Knud Rasmussen obtained the distribution of population between Bathurst Inlet and the Mackenzie River from the Eskimo whom he visited in the spring of 1924. For each settlement and camp he recorded the inhabitants of each house by name, including more than a hundred households. He also identified immigrant families from northern Alaska and elsewhere (Ostermann, 1942, pp. 36–44).

Another area where physical mobility needs to be studied by means of genealogies is northwestern Alaska, particularly the region from Deering to the Kobuk villages, from Anaktuvuk Pass to Wiseman, and from Barrow to Kotzebue.

The cost and physical difficulty of field work in these areas, especially the Canadian Barren Ground, and the social and emotional obstacles raised by reluctance to discuss the dead are great. No other kind of study, however, will give so many data useful for so many purposes as will good genealogies, which should include the usual information on the place and supposed cause of death, sequence of marriages, and adoptions.

Other specific studies should be made of the following problems:

1. *The effect of epidemics on social groupings and geographic distribution of people:* Poliomyelitis epidemics in a few localities between Hudson Bay and the Alaska boundary in recent years might provide useful starting points for this study. The facts to be ascertained include the number of families affected by death or paralysis that combined to help each other hunt and travel, the pre-epidemic relationship of these people, the number that moved elsewhere permanently, and any changes in relationship between Eskimo and white men brought about by the experience.

2. *Birth rates compared with trends in size of adult population and of abortion and premature birth rates:* Recent information shows that the Eskimo population in Canada and Greenland is now increasing. Studies should be made of the reasons for its decline at certain times and also of the present situation in Alaska, where the Eskimo population is more static than in Greenland. In a declining population are there simply not so many births or are both birth and mortality rates high?

3. *Change in population size compared with change in the volume and variety of the natural resources utilized:* Regions where, because of scarcity

of resources, there is a real population pressure, no matter how sparse the population is, should be identified. Full development of this large research problem would probably require study of the past as well as the present size and pattern of settlement. There is much information from Greenland and some from Canada and northern Alaska, but almost none for southwestern Alaska. The practical problem of uneconomic Eskimo settlement has already received much attention in Greenland, especially on the east coast, and in northern Labrador. In Alaska, the areas needing prompt attention because of serious economic pressure are the Aleutian Islands, the Alaska Peninsula, and the tundra between the Kuskokwim and Yukon rivers.

4. *Numbers of persons in the advanced age-brackets, their location, and their support*: We know in a general way that there has been a big change in the Eskimo's treatment of their aged. But our knowledge should be more exact. In this example of reaction to changed culture (specifically changed morality), we have a welfare problem because maintenance of the aged affects food-sharing, composition of the household, and other material as well as social conditions.

5. *Effect of any changes in customs of adopting young children*: Again, we need to know exact figures on adoption and its effect on the household.

Evidence from biology and geography, or, better, from a combination of these with anthropology

1. *The social and emotional factors affecting the hunting of caribou and herding of reindeer*: The resistance to reindeer-herding apparently goes deep into the Eskimo value system. It involves not just habits but also factors of prestige and religion. If we can understand this resistance, we probably will understand much of Eskimo culture. In caribou hunting, the continuing or changing tabus, folklore, rational lore, and emotional factors, now possibly modified by the use of guns, need attention. Because caribou have been a staple and because in some places reindeer might also be, this study has basic survival value. It could best be made in sample areas in Alaska and possibly in Canada.

2. *The Eskimo's scientific knowledge of plant and animal life, and human anatomy*: Although many people have said that the Eskimo had aboriginally a remarkable knowledge of their natural environment, only recently have field workers been recording this scientific knowledge, with proper identification of species and organs, in a comprehensive fashion. William Laughlin (Laughlin and Marsh, 1951) and T. P. Bank, II (1953) have independently worked on this problem in the Aleutian Islands, and Laurence Irving has begun a similar study of the inland Eskimo of the Brooks Range. These observations should be extended to other localities.

3. *Occurrence of fishes and other resources not now developed*: There is obvious need to know why a resource has not been used, any economic

changes and technical requirements for its development, such as larger boats or dependable water supply, and the factors affecting its abundance.

4. *The uses of aircraft for getting knowledge of natural resources and their utilization*: This study could best be made in Alaska, where bush pilots and small airlines are more numerous than in Canada or Greenland, and where aircraft have already been used for locating caribou herds and the concentration and movements of other animals, for carrying frozen fish and reindeer meat to local markets, and for informing the local people of sea and river ice conditions. The knowledge obtained would principally benefit the Eskimo in Canada and possibly also in Greenland. As a partial alternative to public relief in the north of Canada it might be worthwhile subsidizing bush pilots to help the native population (*see Arctic*, Vol. 5, pp. 193–5). Often Eskimo need to be transported or guided to better areas for caribou hunting, fishing, or trapping to take advantage of seasonally more abundant resources.

Studies of adaptation to natural environment, using chiefly archaeological and ethnographical data

The following problems need attention, and there appears to be enough material to make a good start. The researcher is urged to avoid reconstructing history just for the sake of history. Whether a people brought an idea ultimately from central Siberia or central Canada does not matter greatly in its local usefulness in building a better house or kayak.

1. *A functional and ecological study of Eskimo-Aleut housing, past and present*: Each local housing-complex should be considered in relation to its site, principles of construction, available materials including the tools, such as mattocks and knives for digging turf, and, where recent groups are concerned, the number of people accommodated, and uses of structures for other than family housing. The mechanical and thermal problems of each local house-type should be analysed and their architectural solutions compared. To obtain evidence of the principles of construction, as well as simply describing the structure, joint field work between an engineer-geologist and an anthropologist would seem necessary. This should include examination of such features as the use of skins, or bark, with turf, wood, and snow, with or without air spaces for insulation, adaptation to slopes (old beaches, kitchen middens) and to permafrost level, and the solution of drainage problems. In considering prehistoric housing, special attention must be given to the climate at the time the house was built. Recent meteorological and glaciological work should make this possible.

2. *A comprehensive study of Eskimo clothing*: It is surprising that a study of Eskimo clothing has not yet been made. It should include data on unusual materials such as bird, dog, and fish skins, fur of small mammals, and woven grass, as well as the usual caribou, seal, and bear skins. The greatest variety of materials seems to have been used in the east Bering Sea area, where, for example, some villages still wear fishskin boots. Adaptations in stitching and tailoring patterns to the various materials and their specific uses should

also be studied. The variety of stitches was greater, especially in southwestern Alaska, than most enthnographers realize. The assistance of a textile and clothing expert would be useful, perhaps essential.

3. *A functional and ecological comparison of the various kayaks and umiaks*: The team needed for this study should include a marine designer and an ethnographer. Data on the rational lore and folklore of the construction and uses of kayaks and umiaks should be obtained soon from the old people, especially in those areas in which plank boats have supplanted the skin-covered ones. Such Eskimo principles as that the body measurements of the kayak-man should be used in constructing his boat might be worth investigating, also the variations in shape and proportions in different areas. Both the local people's explanation of adaptation to shore and ice conditions and the observer's explanations would be necessary. In many places it will be difficult to reconstruct an adaptation which is already outdated, but undoubtedly something can be retrieved.

4. *A new survey of types of dogs and their uses*: A person or a team with technical competence in both mammalogy and ethnography would be required for this survey. The emphasis of the study should be on dogs and on man's use of them, as affected by religious belief, social-status value on dogs, and the importance of dogs for food and fur, rather than on sleds and hitches. Although much has been written about Eskimo dogs, further work is necessary because new breeds have been found in the archaeological discoveries of recent years, for example Haag's "Large Kodiak Island Dog" (1948). In southwestern Alaska where dogs were not needed for sledging on sea ice, they may have been used for packing, and a big strong animal may have been preferred. The area around Goodnews Bay and Bristol Bay, a gap in our knowledge regarding most aspects of Eskimo culture, would be particularly interesting for this study. Because of culture loss and forgetting, it would not be easy to get information, but something could be learned about changes in the ecological place of the dog.

5. *Case histories of the annual cycle*: The social and ceremonial, as well as material, factors influencing families' decisions to move for the various kinds of fishing, hunting, trapping, and wage work should be recorded. This kind of research requires close acquaintance with the people, real frankness, mutual reliability, and an understanding of the mechanisms of rationalization. It is important because in some areas poor decisions on places for hunting and caching food can be a matter of survival.

6. *A thorough ecological study of one community*: Two areas suggested for such research are the Yukon delta and the lower Kuskokwim River. Such villages as Akulurak and Pastolik around the delta would be good for a study of the importance of birds and fish in this rich bird-breeding area, as compared with that of sea-mammal hunting. The region at the mouth of the Kuskokwim River has many similarities to that at the mouth of the Yukon, but it is less specialized. Villages like Kwigillingok near the mouth of the Kuskokwim River could be compared profitably with others along the coast, as well as

with those farther upstream where there is no sea-mammal hunting. Lake fish and small fur-bearing animals are used by the people in these areas as sources of food and clothing materials. In Canada the Perry River region might be good for showing a combination of inland and coastal hunting. Finally, a re-examination of the groups that Franz Boas knew on Baffin Island is about due.

These studies should be quantitative and not limited to the pattern of relationships between human communities and environment, expressed in general terms. They should ascertain the species and number of birds and animals killed within a given period of time, the quantity of fish taken, and the gear used. The community should of course be assured that the anthropologist or zoologist is not a game warden. Function-and-form studies will be needed when considering human use of resources. New materials can be used for old purposes, for example an empty five-gallon gasoline can in place of a sealskin float. Or an old material can be given a new function, for example ivory napkin rings made for sale. Many changes, however, are more complex and difficult to discern. Man approaches a new environment not merely with needs and habits but also with ideas about the proper way to do the jobs confronting him. The observer's task is to see how he implements his ideas, how his very perception of the environment is affected and limited by his preconceptions, and how in time he changes the ideas and redefines his situation. The materials that are found and used will influence or limit in turn the form of implements and ultimately perhaps their whole function. Generally, though, the function is the most durable, for ideas can at times be even more influential than the natural environment. Verbal tradition adds, for human ecology, another dimension to those of the remainder of the animal world.

Adaptation to social and cultural change

So much research is needed on adaptation to social and cultural changes that it is difficult to know where to begin. The cooperation of economists, sociologists, and psychologists on most projects in this field would be necessary.

1. *Economic and social effects of a technological change*: One important change is the shift from skin-covered to plank boats. A study of this change might well be made in conjunction with the project on kayaks and umiaks (p. 313, No. 3). A start has been made in Berreman's work on Umnak Island (1954). The whole question of the present adequacy of locally owned boats should be considered. It has been suggested, for example, that the Scoresby Sund people should have larger boats so that they can go farther into the fiords for hunting (Mikkelsen and Sveistrup, 1944, p. 118). Tanner expressed surprise at the substitution of heavy plank boats for kayaks by Eskimo on the east Labrador coast, since these boats are not so well suited as kayaks, he thought, to seal hunting at the floe edge (1944, p. 529).

The prestige value of the different kinds of boats, their practical usefulness, the cost of importing or building, the cost of maintenance and means of

financing, the changes in travel, and economic activity directly traceable to the new boats are all problems to be considered.

Although the umiak has disappeared in most areas, it is still used and cherished in the Bering Strait region. The changes that have adapted it to modern needs are taken for granted locally, but are not known to many outsiders. Factors influencing adaptive changes and continued use of skin-boats might provide an instructive contrast with factors favouring the new means of water transportation elsewhere.

2. *The process of adaptation under urgent economic pressure*: Because of disastrously poor salmon-fishing in 1953, some of the Bristol Bay canneries had to close in 1954. The sudden diminution in the long-established commercial fishing industry will require a readjustment in local economy, modified and perhaps directed by a government program. This problem begs for immediate attention, for scientific as well as humanitarian reasons.

3. *Reaction to resettlement*: The removal of Thule village and the future move of Aklavik provide opportunities to study this problem, which is not so common today as it was in the nineteenth and early twentieth centuries, when epidemics, the whaling fleet, and the first establishment of trading posts and missions forced or encouraged Eskimo to relocate their settlements.

It would be interesting to determine whether or not individuals' places within the social system change or whether the system itself alters in the new physical situation. For example, do new leaders appear, and if so, by what means? Are there greater opportunities to become prosperous and greater opportunities for leadership in community planning?

The movement of people from outlying districts to large central villages and towns must be considered, especially in Greenland and Alaska. What changes in occupation, in relationship to natural resources, does this movement foster or require? What are its effects on family and community organization?

4. *Changes in relations between Indians and Eskimo and the nature of the relationship in one locality*: The Mackenzie delta seems to be an excellent place for such research. Some aspects to be considered are the possible and the actual personal relations in such matters as recreation, religion, and work; competition between the two peoples, and the nature and scarcity of the things for which they compete; superordination and subordination in the over-all status system, and the white man's preference for one ethnic group over the other. Honigmann (1951, 1952), in his study of Eskimo–Indian–white relations in the Great Whale River area, has shown what can be done in even a short field study. Similar research in other areas would also be useful.

5. *The process of adaptation in one clear-cut change in a social situation*: One such change is the shift of a village school in Alaska from the federally supported and administered Native Service to the Territorial Department of Education. Year by year more schools are shifted from one system to the other. The two school systems have different philosophies and policies of education, teachers are hired for different periods, and their extra-classroom

duties are different. The processes of reaction in the community are likely to be complex, and there may be unforeseen reactions in the school system itself. This is a study to be made periodically through two or three years, emphasizing the process itself and describing the causes and relationships of the various steps in the change. Pre-judging of this changeover should, of course, be avoided.

In Canada, as well, the appointment of welfare teachers where there have been none, or at least no government-supported teachers, will promote local changes that require attention (Grantham, 1951).

In Greenland, the teaching of Danish in the lower schools, although not so big an innovation as the initial establishment of a school, is also likely to start an interesting chain of development. The study of any European language affords new literature and experience, and at the same time establishes a linguistic division in the community.

6. *Effect of an administrative rule on family organization and community relationships*: For example, the changes traceable to policies in granting Family Allowances in Canada or the Aid to Dependent Children in Alaska should be studied.

7. *Effects of a public health program on other aspects of life besides health*: The rehabilitation of arrested tuberculosis cases in both Alaska and northern Canada is especially worthy of research. It would be well to consider the role of the returned patient as an innovator, and to note his effect on old concepts of disease and medical practices. There are also important questions to be answered in psychology, but they cannot quite be conside ed ecology.

8. *Effect of rapid increase in contact with the larger "outside" community*: Greenland's relation to Denmark, and indeed to western Europe and eastern North America, has become so much closer since the Second World War than it was before that the cultural environment, except possibly for the far northern settlements, is almost new. Previously the outside culture came through the church, or second- or third-hand through a few Danes resident in Greenland. Now by means of such things as the radio, adult education in Greenland, advanced education of young Greenlanders in Denmark, trade contacts, and political participation, the Greenlanders are experiencing Danish culture directly. It should now be ascertained whether there is a conflict, especially for young people, between local authority and that of this larger community. Are there new concepts of property and wealth and is property handled differently as a result of the introduction and the rapid expansion of private enterprise in commercial fishing, of new methods in sheep raising, and of taxation? Are changes in the personality or national character of Greenlanders visible between the middle-aged and the young adults? If there are consistent differences, they might be related to the expanded culture of Greenland.

9. *Form-and-function relationships in non-material aspects of culture*: Form-and-function studies of the technology have already been mentioned. An example in non-material culture is the present social meaning of Christmas,

which has become a very big event in many Alaskan Eskimo villages and apparently also in Greenland. In Alaska it seems to have taken on many of the old psychological, social, and economic functions and some of the old religious function of the Bladder Festival, the Messenger Feast, and other hunting festivals. (In the east Bering Sea area these festivals were formerly held in or near December). These impressions need to be tested, possibly by formulating hypotheses regarding the degree and kind of borrowing from pre-European ceremony. This celebration seems to be an example of local re-interpretation of a new form, and transfer of a function from an old to a new form of ceremonial.

10. *The impact of Christianity on beliefs and practices concerning nature*: For example, the effect on food resources should be studied. Are there new protectors of the game animals and new sources of guilt feelings relative to hunting practices, and new concepts of wrong-doing with regard to the natural world? Are there new explanations of natural phenomena? How satisfactorily do new ritual and beliefs replace the old in fulfilling the material and emotional needs of the Eskimo?

11. *A regional survey, including most of the above problems*: Labrador seems to be the most promising place for this survey, as Tanner (1944) has already compiled much of the necessary background data, not only on the natural environment but also on the introduction of disease and the establishment of missions and trading posts, in a brief historical review. Some of his explanations of cultural reaction will require re-examination, but his observations made in 1939 would provide interesting comparisons with current observations. Moreover, his suggestions that the geographic extent of the Eskimo was related to the distribution of the seals (p. 478) and that their withdrawal was related to the settlement and behaviour of white men and Indians (pp. 479–82) should certainly be considered.

Hamilton Inlet in Labrador is the only place where a white community (in contrast to occasional missionaries, traders, or travellers) has taken up the Eskimo system of seal hunting at blow holes, using the sealskins for dog harness and clothing, and eating the meat of the young seals. It is therefore an excellent area for studying the mutual exchange of cultures. Labrador has had a settled white population, making its living from the country, rather than from ministering to or administering the aboriginal population, longer than have most parts of Eskimo territory. Despite the numerous semi-popular writings on Labrador people, there is still a good field for social anthropological and ecological research on all three ethnic groups in east and north Labrador.

Balancing of factors in ecological adaptation

To see the direction and progress of a people's total change, the biological and cultural factors must again be considered, but in different ways.

1. *Factor of health in total behaviour*: It is important to consider the diet and health of individuals, that is, their physical and emotional capabilities, as well as their motivation and cultural equipment when judging their prospects

for making use of any given resource, whether it be a technical training program or the introduction of reindeer.

2. *Adequacy of cultural substitutions made in the course of acculturation*: Before considering the integration of the whole way of living, it would be well to make an inventory of the changes occurring in sample villages. In which elements of culture has there been an absolute loss, with nothing to replace the old skills and old means of achieving prestige? In which has there been an absolute gain? What substitutions have occurred, such as that of rubber boots for oil-soaked sealskin boots? How adequate are the substitutions in satisfying basic needs? For instance, how does the new community control of anti-social behaviour compare with the old? What are the effects of new forms of art on aesthetic expression and recreation? Do both young and old men now do carving and what materials do they use, do the old people know the new popular music, and do women have new means of artistic expression? Finally, how does the present recognition of life crises compare with the pre-European? Are new life transitions recognized or ignored? For example, a boy was honoured for the first seal or bear he killed, but is he likely to be honoured publicly for his first regular, paid job?

3. *Balance of integrative and disruptive factors in a local situation*: Improved health care, new sources of income, legal protection, and other measures for human conservation may be outweighed by the loss of craft skills and the greater need for money to buy tools and other goods, by economic and personal waste in excessive use of alcohol, by religious and ideological conflicts, by competition for satisfactions rarely attainable, and by community disorganization and loss of self-respect. The decrease in murders and accidents may be outweighed by the death of tubercular patients. On the other hand, a conflict between the village and the trader may be less disturbing than a former conflict between the settlement and a member accused of sorcery. The research worker should try to identify and evaluate both destructive and constructive factors. It is especially important not to overlook the subtle psychological factors that may build up or tear down a people's self-esteem and morale. Loss of these can destroy a people's will to adapt.

4. *Local awareness of ecological problems*: Many ecologists have paid little or no attention to people's ideas about the demands and benefits of their own environment, and about their own ability to deal with it. We hear most dramatically from some Aleuts, but perhaps we could hear elsewhere if we would listen, a conscious acceptance of the fact that they are a dying people, hopelessly facing extinction. In other cases Eskimo want to fight for life and perhaps know better than their white administrators what they need in order to deal with their difficulties, although they are seldom asked. It would be useful to find out just how much they do understand of their changing environment.

No specific research projects are suggested here on the substitution of commercial fishing for sealing along the west Greenland coast, although it is

the biggest change in natural resources in the past fifteen years and has resulted in serious cultural changes, since this shift has already been given much attention.

In concluding this account of suggested research projects, four recommendations, which apply to almost any ecological study, should be emphasized:

1. Group research is needed. Different disciplines should be concentrated on one time and place. Too often research workers try to relate the culture of seventy-five years ago with the distribution of fauna today, failing, moreover, to see fauna through a biologist's eyes, and to interpret culture with an anthropologist's understanding.

2. Specific ecological field research is needed to replace the usual system of taking ecological data from material collected for other purposes. For better focused and delimited field research, hypotheses should be formulated and tested.

3. The study should be repeated at intervals. Human adaptation, especially in this period of frequent innovation, is a step-by-step process. In technology this is clear. We can visualize and understand what is involved in the mechanical process of printing a newspaper or the process of making a pottery bowl. In making a new cultural adaptation, the same basic principles operate: certain things cannot happen until certain other things have happened. Hence in any study of process, frequently repeated observation is necessary.

4. Finally, the criteria of adaptation should be stated. Certain changes that seem to the casual observer to be unadaptive may actually be adaptive from the standpoint of community solidarity or of the self-respect of the Eskimo. Conversely, economic aggressiveness and acceptance of new means of livelihood may be good adaptive behaviour in one segment of life, but at the same time may disrupt the extended kin-group responsibilities and induce social disorganization, at least for a transitional period. Disorienting and disorganizing tendencies are almost always present along with the integrative and reconstructive ones. The student's task is to assess their balance, and to try to predict which way it will tip.

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HUMAN GEOGRAPHIC RESEARCH IN THE NORTH AMERICAN NORTHERN LANDS*

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Few people would doubt that northern North America needs more people. Nor is there much question that the region can support and will have a greater population in the near future. Further, the usual assumption is that the additional people should or would be permanent rather than temporary inhabitants. It is necessary therefore to consider the human geography, or the locational characteristics of the present and future population distribution. This analysis reveals the significances of the relative locations of people to people and land to people. In this broad field the following topics and problems have been selected to demonstrate the great range and promise of such research in northern North America.

Basic hypotheses

First, the regional extent of the Northern Lands needs defining. Existing boundaries are based largely on physical elements of the landscape, possibly because there have been more physical than cultural measurements. The regional boundary shown on Fig. 1 summarizes a series of cultural as well as physical characteristics. This arbitrary southern limit includes all of Alaska and Greenland and extends through southern Canada so as to include parts of the northern edge of continuous white settlement in North America. But how else may the regional limit be drawn?

The relative significance of northern North America to the population of the rest of the world needs to be determined. For example, thinly settled Alaska and the Canadian north have been considered as possible areas to absorb world over-population (Hewetson, 1946; Sandwell, 1950, p. 162; Warren, 1941, p. 167). But are they significantly so? Certainly not for the many European refugees who are largely city dwellers with few possessions and with occupations not yet needed in unsettled Alaska and Canada (Warren, 1941, p. 167). Perhaps not, also, for European and Oriental agriculturalists since economic or physical conditions would require different methods of farming from those to which they are accustomed. Yet people in modest numbers and with certain occupations, such as skilled labourers, might be absorbed from some of the present highly populated parts of Europe and North America.

*Supported partially by aid from the University of Wisconsin Graduate School Research Committee.

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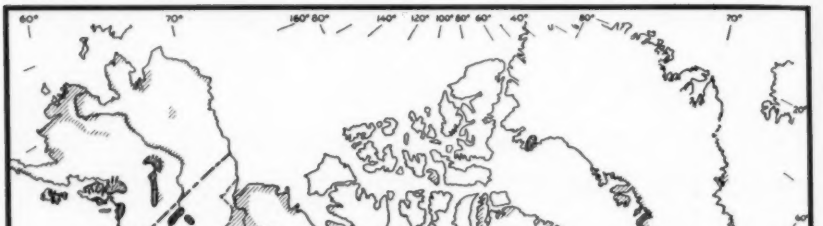
NORTHERN LANDS SETTLEMENT
Southern limit of Northern Lands
Northern edge of continuous white settlement (includes some native settlement)
Advancing frontier of white settlement
Stable frontier of white settlement
Retreating frontier of white settlement
Approximate area of clustered and relatively permanent native settlement (includes some white settlement)
0 200 400 600
MILES
GEOG. DEPT. UNIVERSITY OF WISCONSIN

Fig. 1.

Northern North America's relative significance varies greatly with changes of viewpoints and time. It has been said that "There are no vital international problems which have their real origins in the northern high latitudes" (Jones, 1948, p. 16). Economically, however, Alaska is a world leader in commercial fishing, the Canadian north in commercial fur trapping and mining and forestry, and Greenland is a primary source of natural cryolite. In recent years, the whole region has possibly become more significant militarily than in any other way. Certainly the region's human geography is being changed drastically by the military developments.

It is sometimes assumed that the historical pattern of expanding Anglo-American settlement will continue. We know that the spread of Canadian population has been continuous and outwards from the original settlement (MacLean, 1933, p. 210); so it has been in Alaska (Stone, 1952) and Greenland (Friis, 1937, pp. 80–5) although from more than one origin in each. But we must question the validity of basing present-day human geographic research in Canada and Alaska on the hypothesis that because settlement swept westward to the Pacific Ocean and thence northward it will continue in this

direction. The "Go west" of the early 1900's is not necessarily "Go north" now. Equally, we should not assume that the expected population growth in northern North America is likely to maintain the steady increase of recent decades. The days of "boom" populations may be over for possibly the whole region. We need now to show the geographic trends for the present population of the North American Northern Lands and to forget the recent Anglo-American experiences of a continuous, rapid, and steady wave of thin settlement to the west and then northward.[1]

Further, we need to beware of subconscious, or conscious, acceptance of the concept of environmental determinism, in whole or in part. Humans may be thought to be controlled by their physical environment, or be a product of it, in the parts of the region which are more difficult physically. However, throughout the world people live in areas largely by choice rather than environmental force and they also select their ways of living. Further, we have seen through history that different people have lived differently in the same section of the north; even now in northern North America there are significant differences in occupations and population densities.

Another concept, often unsaid, is that any exploitation is only temporary. This needs testing. Present settlement based on non-renewable resources might be assumed to be temporary because the resource can be removed completely. However, do we anticipate losing the whole population of the Lake Superior ore ranges with the area's decline in production of iron ore? There is a semi-permanent, if not permanent, settlement in northern Sweden where the Kiruna iron mines are producing on a plan which extends production at least two hundred years into the future. Similar permanence might well be expected at the new Labrador iron mines and elsewhere?

If these non-renewable resources may be expected to last for long periods then we may certainly expect more permanence of settlement based on extracting renewable resources. There will naturally be fluctuations: fishing grounds, forests, and fur producing areas may be depleted by unwise use, or the persistence of settlements may become difficult because of economic trends. However, there is little evidence to justify an assumption that population based on exploitation of local renewable resources will not last as long as that based on, say, processing foreign resources. Furthermore, there are numerous examples of abandoned agricultural areas in the world to remind us that agricultural settlement is not necessarily permanent.

Is is often assumed, though, that new settlement in northern North America will be based on agriculture and some research has been improperly or unnecessarily limited by this idea. In two accounts nearly the whole North American Northern Lands, as shown on Fig. 1, is mapped as being "unfavorable to settlement" or "negative settlement areas" while the analyses are largely in terms of the agricultural future only (Broek, 1941; Stamp, 1952, p. 49); actually relatively great non-agricultural population increases have since taken place in the area. Another author mapped the future population density of Canada

[1]It is dangerous to accept such statements as "The settlement of this vast area [Canada] will follow along the lines indicated by the settlement during the last three centuries . . ." (Taylor, 1946, p. 71).

entirely in terms of the limits of certain crops (Taylor, 1946, p. 72). It is refreshing, however, in other Canadian accounts to find fishing, lumbering, trapping, mining, and petroleum developments considered as bases for future developments (Hewetson, 1946; Mackintosh and Joerg, 1934–40). To these may be added the rapid, and presumably permanent, population growth based on water power and tidewater location at Kitimat, the new lead mine at Mesters Vig in east Greenland, as well as Dawson's suggestion that agriculture, in the Canadian northwest at least, is likely to be based only on local demands which originate from non-agricultural occupation in the region (Dawson, 1945, p. 584). We need more of this completeness of analysis and denial of assumption that the future population will be rooted permanently only through agriculture.

Another hypothesis to consider about future settlement is whether it could or should be self-sufficient. There are, of course, varying degrees of self-sufficiency. However, specialization has accompanied much of the world's development, particularly in the mid-latitudes from which growth has spread to the adjacent Northern Lands. There are few expanding economies today which do not include increasing specialization, such as the cod fishing in Greenland. In times past, when people in cities had only a few more conveniences than those in rural areas, new settlers could be fairly self-sufficient and could accept the somewhat less convenient frontier life. Today, technological developments and the improvement of transportation and communication facilities generally have increased the differences of living in old and newly developed communities and have made it possible for new settlers to be constantly aware of what they are missing. Under these circumstances it appears wise for human geographers to prove whether or not future settlement should be thought of in terms of: specialized developments, combinations of specialities, or as frontier life with amenities unknown on the frontiers of the past. In the past, rural farm populations in Canada have spread over an area near the Northern Lands but as numbers of people increased the poorer lands were abandoned (Lemieux *et al.*, 1934). Should we not restudy this situation to see if the present movement of frontiersmen should be restricted to that land only which is best for the occupation proposed?

Hypotheses formed on assumed evidence must, of course, be resisted. A common belief is that persons from Scandinavia or the north-central United States are the best settlers in Alaska. Many experiences have shown the contrary. Similarly, lengthening hours of sunlight with increased latitude were thought to shorten periods of plant growth. Now we know that the reverse is true, that moisture and temperature are quite important, and that selection of plants for experimental growth is as complex as the selecting of new settlers.

In general it is clear that more thought and research on the basic hypotheses of frontier settlement are sorely needed. Much more information is required on both the physical elements of the landscape (Flint, 1950) and the human, or cultural, landscape (Keenleyside, 1950) before the North American Northern Lands can be developed wisely.

Population enumeration

There were approximately 937,000 people in the North American Northern Lands in 1951 (Table 1). These were composed of about 25,000 Eskimo, 22,000 Greenlanders, 80,000 Indians, and 810,000 white people. However, human geographic research depends on accurate, current, and detailed population data for specific areas and the problem is how to obtain such information.

Table 1. Estimated population for North American Northern Lands, 1951.

	Total	*Estimated portion in Northern Lands*
Alaska[a]	128,643	108,000[b]
Canada[c]		
Northwest Territories	16,004	16,004
Yukon Territory	9,096	9,096
British Columbia	1,165,210	20,000
Alberta	939,501	80,000
Saskatchewan	831,728	60,000
Manitoba	776,541	30,000
Ontario	4,597,542	110,000
Quebec	4,055,681	120,000
Labrador	7,890	7,890
Newfoundland	353,526	353,526
Greenland[d]	22,890	22,890
		(about) 937,000

[a]'United States census of population: 1950, Alaska, general characteristics', 1952. Washington: U.S. Dept. of Commerce, Bur. of the Census.
[b]Excludes 20,643 military personnel on duty in Alaska.
[c]'The Canada Year Book, 1952-53'. 1953. Ottawa: Dom. Bur. of Statistics, p. 128.
[d]'Report on Greenland, 1953'. 1953. Copenhagen: The Prime Minister's Second Dept. p. 2.

Improvement of the reliability of the censuses is a fundamental need. Much of the native population is mobile, being at fishing sites in summer and at hunting sites in winter. There is the risk of counting such people twice or not at all and it is clear that data may not be comparable if the censuses are taken at different times of the year, as has happened. Also, it is difficult and expensive to count relatively few people widely separated in such a large area as northern North America, and improved counting techniques are needed.

Northern population figures do not remain current for long, even if they are reliable. In Alaska, for example, the 77 per cent increase from 1940 to the 1950 figure of 128,000 people was the most rapid under the United States flag for the period. Yet the estimated population changed to 152,000 in April 1951, to 182,000 in April 1952, and to 199,000 in April 1953.[1] By the time Fig. 2 was completed for distributional analysis the population had increased more than 40 per cent! Thus, human geographers need to perfect rapid estimating of current population in northern North America and to aid quick publication of population maps and data.

As yet, the detail of census data is insufficient for analysis. Throughout northern North America the enumeration districts are too large for specific location of a population which is mainly (60 to 90 per cent) clustered in small groups. Usually official populations for unincorporated settlements with fewer than 25 people are grouped in district totals, thus making difficult the

[1]'Estimate of Alaska population, January 1, 1950–July 1, 1953'. 1954. Juneau: Office of the Governor, Alaska Development Board, Alaska Dept. of Health, pp. 5–6.

locational analysis of the large percentage of the population that lives in small settlements. A partial solution for this problem may be the "postcard censuses" taken by publishing companies, such as Rand McNally and Company. Also, population data by race at each settlement are often unavailable for past censuses. A frustrating example is the Alaskan 1920 census in which all Indians, Eskimo, and Aleuts were reported simply as "Natives". For Alaskan censuses special tabulations by race for settlements with more than 25 people may be purchased by special order whereas in Canada dependable details for Eskimo settlements can be obtained for the 1941 and 1951 censuses only.[1] Until such detailed data are generally available human geographic research is likely to remain on the too-small scale of large political (Veyret, 1953) and census divisions, which are geographically artificial, or the too-large scale of special studies of very small areas.

Population distribution

Analysis of population distribution is the core of human geographic research. In northern North America at least five generalizations may be made about the location of people: much of the population is in the southern parts of the region, settlements are largely on water bodies and primarily on coasts and large rivers, the people are clustered unevenly throughout the region, there have been significant changes in regional population patterns in recent times, and the explanations for the past and present distributions are complex and only partly known. But we need to know to what degree these generalizations are based on or may be supported by human geographic research.

Locational analyses are based on maps. Therefore, human geographic research must be preceded by the compilation of the available map and air photo coverage. For Alaska this has been done, but only partly so for northern Canada and for Greenland (Stone, 1954; Stone *et al.*, 1953). Also, the maps available need improvements in completeness and accuracy as well as enlargement in scale. Coverage of the whole region is available on the 1:1 million aeronautical charts and for much of it on 1:500,000 topographic maps. However, these scales are too small for the direct mapping of the form and function of settlements. Both of these may be interpreted, though, from the air photo coverage which is available for most of the region. These photos are suitable for detailed research where 1:20,000 to 1:40,000 verticals are available but the photos are often unsuitable for detailed interpretation in the large areas covered by oblique photography only. There is, therefore, serious need for improved human geographic mapping methods as well as for indices of the current map and photo coverage by areas and types. Human geographers should share part of the responsibility to prepare these indices.

In addition, there is a shortage of air photo interpretation aids for human geographic research. Procedures have been outlined (Stone, 1951), but no

[1]The problems of taking the census of Canadian Eskimo are noted in: "The 1951 census in the Northwest Territories" and "Population of Eskimo peoples". 1954. *Arctic*, Vol. 7, pp. 52–5.

Fig. 2.

specific interpretation aids are generally available for arctic and subarctic settlements or uses of land. Because air photos are one of the basic sources for North American research, the immediacy of the need for interpretational experience and published aids, particularly in human geography, is emphasized.

Distribution of population maps for the region are scant and inadequate. There is pressing need for one for the whole region on a scale of, perhaps, 1:5 million, with a carefully designed population breakdown. The distribution maps now available for the major political parts of the region show the coastal and riverine concentrations properly but are out-dated, small in scale, or not comparable in the divisions of population.[1] Racial distribution analyses are as scarce. For example, the most recent published analyses of Canadian Indian distribution and Alaskan native locations are based largely on observations of the 1930's.[2]

Mapping population distribution leads immediately to a basic question: What are the significant units of size? For Fig. 2 the system of doubling numbers was employed largely for the visual simplicity of doubled areas of the circles for groups of increasing settlement size. From field observations

[1]*See*: Map of "Distribution of population, Canada, 1951" *in* 'The Canada Year Book, 1952–53'. 1953. Ottawa: Dom. Bur. of Statistics, *following* p. 128; Friis (1937, Fig. 7, p. 81); and U.S. Air Force, "Density of population chart; northern hemisphere". 1947 (revised). Washington: Aero. Chart Serv.

[2]Jenness, D. 1932. 'The Indians of Canada'. Ottawa: *Nat. Mus. Can. Bull.* No. 65; and 'House Report' No. 2503. 1953. Washington: U.S. Congress, House of Representatives, 82nd Congress, 2nd Session, Addendum IV, pp. 1,406–1,537 and Maps Nos. 156 and 157.

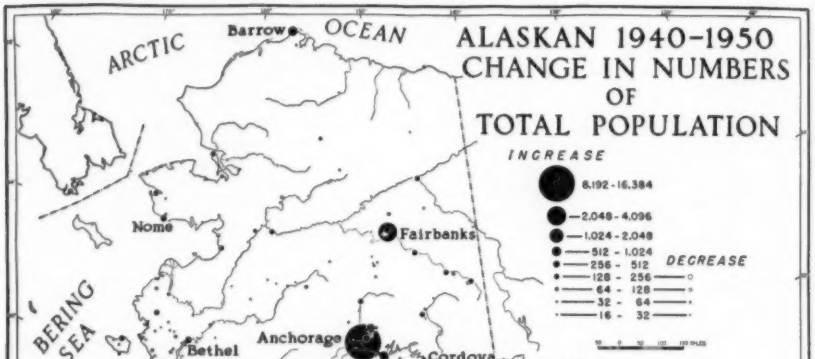

Fig. 3.

it is felt that the lower divisions shown are significant groupings of the population. That is, from the smaller to larger numbers the classes represent villages of increasing permanence of settlement. However, the classification is too subjective, particularly in the classes of more than 1,024 people. Further, should the Eskimo, Indian, Aleut, Greenlandic, and white settlements all be classified in the same system or separately? For example, a frequency analysis of the 1950 populations of Alaskan natives in settlements shows these groupings: Aleut 10–80, 80–180, and more than 180; Eskimo 10–80, 180–270, and more than 270; and Indian 10–50, 50–210, and more than 210. Perhaps this statistical grouping of settlement sizes is significant. Or, more likely, should a combination of size, area, race, and occupation be used in grouping populations? On this we sorely need experimentation.

On large-scale population maps the research may be in terms of density rather than individual settlements. If so, again there is need to determine what the significant classes are rather than selecting round numbers, such as 5, 25, or 100. Per-square-mile figures in areas of agglomerated settlement are of questionable value whereas more significant are the per-mile-of-coastline densities as have been used in analysing Canadian native settlement (Kroeber, 1939; Robinson, 1944).

Distribution of changes in population have been studied little in northern North America. Figure 3 is an example of what is needed. It shows the well-known heavy concentration of the Alaskan 1940–1950 population increase in the Anchorage area. Less well known and possibly more significant is the

concentration of decrease of population in the smaller settlements of southeastern Alaska, perhaps directly related to the decreased fish pack in recent years. However, these growth figures represent only the total changes in settlements, thus clouding locational differences of change related to variations in sex, race, and occupation. It is known, for instance, that changes in Alaskan white population (Stone, 1952) differ from those of the natives and it is suggested that the same is true, for example, of the Canadian inland and coastal Eskimo. There are many additional examples of such research needed in Greenland and Canada.

Historical geographic research on population distribution is desirable to supplement current investigations. Where, for example, did the Indians, Eskimo, Aleuts, and Greenlanders live in the past in northern North America? What are the relations of those locations to present distributions and why the changes, if any? In Alaska there are indications that the Indians now occupy about the same areas as they did when white settlement began whereas the Eskimo are presently in a smaller area. Detailed analyses to verify these generalizations are in progress but the same kind of research is essential for Canada and Greenland. The general locations of abandoned early Eskimo settlement are known for the northern Alaskan coast, in the southeastern Queen Elizabeth Islands, and on the eastern Greenland coast. However, additional investigation is necessary to determine why the people were once there, but are no longer. Further, "Even today . . . we are still unable to speak with assurance on the origin and affinities of the Eskimo race" (Collins, 1951, p. 440).

Population growth needs to be analysed locationally in terms of birth and death rates. This might show regional needs for better nutrition or sanitation. Further, determining how to measure mobility, often more characteristic than stability at a single site, would be of great significance to the understanding of the northern native population. It is probable, for example, that on Fig. 3 the increased population of the Yukon–Kuskokwim delta is partly a result of Eskimo occupying sites in 1950 that they were not occupying in 1940 because of differences in the months when the censuses were taken of people living at two places each year.[1] It would be desirable to analyse and depict a changing population in terms of areas, distances, seasons, and types of mobility rather than in terms of fixed sites.

Human geography also involves analysis of function and form of settlement. It is likely that regional and sub-regional delimitations of types of commercial and subsistence occupations will help to anticipate the population potential of an area under a given culture. So would research on the kinds of permanent and temporary residences, the shapes of the villages, and the size and location of the areas upon which each settlement depends. Such study has been initiated (Adams, 1939, 1941) and recently stimulated by research of both applied and theoretical values (Rumney, 1949; Shimkin, 1955).

[1]The number of symbols depicting decreased settlement in the delta area does not equal those showing increase primarily because many of the 1940 locations cannot be determined. The 1950 census was taken on April 1 while the previous enumeration was on 1 October 1939, when the natives were likely to have been at a different type of site.

For existing settlements human geographers need to devise measures of the permanence of occupation. These measures will involve different ways of making a living at one site, some of the ways being exploitive. But what else is significant? The number of stores, acreage of cleared land, construction of public utilities, residential building materials, incorporation of settlements, and attitudes of the people? Only the testing of possible measures from present settlements and historical analyses of representative ones—representative of different cultures, occupations, and locations—will produce scientific results useful in the analyses of present and future settlements.

It might be said that there can be no permanence of white settlement in northern North America without good transportation. Thus, challenges are present for human geographers to prove how much permanence of settlement is a product of various types of transportation in areas of varying occupations. Exemplary studies have been done on the significance of the Mackenzie River (Lloyd, 1943) and the Hudson Bay Railway (Innis, 1930). However, there is need for continuing research on these lines of circulation. Even more, planners should have analyses of the significance to the areas traversed by the railroads to Moosonee, Lake St. John, Waterways, and Hines Creek, and of the roads in these areas as well as in the southeastern quarter of the main part of Alaska. These studies would be somewhat historical in nature but present-day analyses should be of value in determining the significance of the Alaska Highway to settlement,[1] of the railroad to the Knob Lake iron centre, and of the new commercial air routes across northern North America.

Further analyses of the permanence of native settlement is a requirement as well. Most of the northern North American natives are largely dependent on animal life for their existence and we know that "In the Arctic, especially, original faunas are so delicately adjusted to their environment that any kind of northern development is likely to have unfavourable consequences for wild-life".[2] Thus, studies of the continuance of native settlement in an area must be closely tied to faunal studies.

Frontier settlement

Frontier settlement research is one of the more fascinating and promising parts of northern North American human geography. Its focus is the edge of an *area* of occupation (a way of living), that is, the zone of settled–unsettled or used–unused land, whereas studies of "pioneer" settlement refer to economy rather than area. Thus, frontier settlement analysis requires great breadth of research involving both the physical and cultural elements of a landscape and leading to the total understanding of man–land relations. The promise of this research is the possible guidance that may be given to present and future settlers to assure their permanence of settlement.

Much has been written on frontier settlement in the past; particularly in the economic depression of the late 1920's and early 1930's when Bowman

[1]In progress at the University of Wisconsin.

[2]Washburn, A. L. 1951. "Geography and arctic lands" *in* Taylor, G. 'Geography in the twentieth century'. New York: p. 285.

initiated pioneer settlement research to aid people in the "back to the land" movement (Bowman, 1931; Joerg, 1932; Mackintosh and Joerg, 1934–40). Since then, interest in the development of principles of frontier settlement has lagged and only a few studies have been made of relatively small areas in the North American Northern Lands.[1] Yet the past twenty-five years have included great changes in the world's economy and big technological improvements, bringing new problems to consider in frontier settlement research.

The most pressing geographical questions are: Where is the frontier and how should it be defined? One location is shown on Fig. 1 as generally between 200 and 300 miles north of the southern edge of the Northern Lands and in a few places extending south of the regional boundary; this frontier is the northern edge of relatively continuous settlement by white people, regardless of their kind of occupation. But perhaps continuity of settlement is not to be expected in the western mountains and, therefore, the frontier really should be farther north and include the settlement of southeastern and southern central Alaska. Further, if the frontier should mark the farthest extent of settlement by any people then the boundary is a very irregular line from 500 to 1,200 miles north of the frontier on Fig. 1.

It is clear that a frontier is defined in terms of arbitrarily selected elements. Thus, there are several frontiers, each of which needs careful definition and plotting on the map. Where, for example, are the frontiers of full-time agriculture, forestry, mining, hydroelectric development, and land transportation? What are their characteristics?[2] Where, also, are the frontiers of white–native contact where problems of adjustment may be quite serious (Fig. 1)? And, by no means least, where is the military frontier? What, for example, are likely to be the temporary and permanent effects of the construction of lines to provide military intelligence in northern North America?

Boundaries involving people are usually dynamic lines. Therefore, human geographers need to analyse frontier settlement in terms of stability. An example is the present limit of continuous white settlement which is expanding in parts, contracting in others, and elsewhere is relatively stable (Fig. 1). It would be helpful to see this classification applied to other types of frontiers, to learn what differences there are in rates of expansion and contraction, and to determine why the motions or stability occur in certain localities. Further research needs are to locate and explain the various types of movement of a frontier: mass movement, "leap-frogging", along fingers, and by encirclement.

Methods of new settlement by native and non-native require analysis. The present resettlement of Quebec Eskimo with Baffin Island families at Resolute and Craig Harbour is an opportunity for study of techniques leading to permanence of native settlement. In Alaska is the chance to learn about, and to aid, the adjustment of the Eskimo at Barrow Village to the substitution of a defence base for a petroleum exploration camp. An example of the

[1] In Canada primarily in the Geographical Branch of the Dept. of Mines and Technical Surveys and in the Dept. of Agriculture.

[2] Agricultural, mining, and forestry frontiers are examples of the suggested type of analysis given in Mackintosh and Joerg (1934–40, Vols. 5 and 9). Recent consideration of these problems is given by Hare (1952).

experiences of white settlement and resettlement has been recorded (Stone, 1950) but of the unsuccessful postwar veteran's settlement at Chilkoot Barracks and the partly successful religious settlements elsewhere in Alaska the records are lacking. Similarly, few reports are available on Canadian settlement during the past twenty years in the Peace River district (Chapman and Gilmore, 1953) and in the Quebec–Ontario Clay Belt (Boucher, 1946; Spence, 1946). However, publication on and planning for the great recent changes in Greenland afford human geographic data which may be useful in some other parts of North America as well as numerous immediate opportunities for applied research (Dunbar, 1947; Greenland Dept., 1953).

Human geographic analyses have already been included in some land classification surveys (Chapman and Gilmore, 1953; Bureau of Land Management, 1947; General Land Office, 1946), and should supplement physical resource analysis in all mapping of the suitability of land for settlement. It was suggested previously that agriculture is not necessarily the sole means of living permanently in a commercial world, particularly when we are considering native occupation. In addition, the function and form of new settlement is as likely to be determined by the new settlers, in the long run, as by the planners. As has been said, "The equipment that new settlers and native residents bring to the new society are as important as the country that receives it, especially the ideas that individuals live by . . ." (Lantis, 1953, p. 30). The human geographer's task is to help produce the harmonious meeting of the settlers' and planners' desires and capabilities in conjunction with the classification of land for either resettlement or new settlement.

The value of frontier settlement analyses for future settlement is unquestionably great. It has been pointed out that land now vacant in the world is usually so because of its marginal nature (Binns, 1951, p. 3; Calder, 1949). If this is true, new settlement will have to be undertaken with caution and will be, therefore, a planned or guided movement of people, rather than a spontaneous one, to ensure its permanence. Such guidance may require governmental participation. And, before the new planned or guided settlements are started research on the advantages of public versus private financing and group versus individual settlement will be necessary. Many other general problems and needs have been outlined (Bowman, 1951). The results of such research could have been used by settlement planners in recent times and are sorely needed at present.

Methods of research

Much of the research suggested could probably be done best by analysts working from general considerations toward the specific. To accumulate sufficient large-scale studies of small areas in order to determine principles or trends will take too long and be difficult, particularly where changes are rapid and great. In the analysis of physical features in northern North America great success has been achieved by starting research on broad areas at small scales and supplementing it with large-scale studies in critical or problem areas

(Hare, 1955). Porsild's work (1954) illustrates the advisability of this procedure in human geographic research.

Also, the historical method can be used successfully to supplement research on current distributions. This is particularly desirable with respect to analyses of frontier settlement and distribution of population. For both topics explanations of current patterns are likely to be understandable in part from historical distributions and the reasons for them.[1]

Human geographic research comparing northern North America with other Northern Lands should be most useful. In Scandinavia, for example, there are settlements much older than in northern North America and which are based on exploitive industries. Have Norway, Sweden, Finland, and Iceland been able to support larger populations longer than in northern North America only because of earlier settlement? Or, is it not because of their proximity to and water connection with the great market and producing area of northwestern Europe?

Only examples of the kind of human geographic research that is possible in the North American Northern Lands have been suggested.[2] The great breadth of research accomplished elsewhere in this field is shown by the large number of topics under human geography in bibliographies.[3] Yet, there are relatively few references on such work in northern North America and these are mainly inventories from which analyses are still to be made.[4] The future of human geographic research in the North American Northern Lands is very promising. It is by such work that the planner, administrator, research analyst, and settler will acquire the data most needed to make secure the present and future population of the region.

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[1]For examples of white population *see* Stone (1952) and for examples of Eskimo and Greenlanders *see* Collins (1951) and Jenness (1944).

[2]Many promising geographers have forsaken research in the Northern Lands because they believed research funds were not available for topics with such broad scope or involving work in distant areas. There are many possible sources of support and those desirous and deserving of it are sure to find it. *See*, for example, Stone *et al.*, 1954.

[3]'Arctic bibliography'. Arct. Inst. North Amer. and U.S. Dept. Def. 1953–5, Vols. 1–5.

[4]Human geographic references in addition to those in 'Arctic bibliography' are in: B. Dietrich. 1930. "Nordamerika" *in Geogr. Jahrbuch*, Vol. 45, pp. 243–300; W. Tuckermann. 1941. "Kanada (und Newfoundland)" *in Geogr. Jahrbuch*, Vol. 56, pp. 357–432; H. Wagner. 1940. "Geography of settlements and population" *in Geogr. Jahrbuch*, Vol. 55, pp. 1–461; Geogr. Br. Can. 1950. "Selected bibliography on colonization and land settlement in Canada"; and Geogr. Br. Can. 1954. "A list of periodical literature on topics related to Canadian geography for the period 1940–1950".

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SETTLEMENT AND TRANSPORTATION IN THE CANADIAN NORTH

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Settlement

Before the European penetration into the north, the native peoples lived by hunting and fishing. They were nomadic, following the animals on which they depended. Some places, such as important caribou river crossings, were particularly favourable for game and were visited regularly at certain periods of the year. Where winter sealing was good or where walrus were plentiful, semi-permanent camps were established, but the need and desire to obtain a variety of food and materials kept the individual families nomadic, or at least prevented them from settling down throughout the year at one place.

This pattern of life was disturbed by the fur trade. Posts were established in proximity to good fur trapping areas so that fur could be exchanged for trade goods. The exact sites chosen depended largely on the requirements of water transportation. Inland posts were on rivers, and coastal posts were located where there were good harbours for discharge of cargo from supply ships. For the native peoples the rifle and other imported equipment made hunting easier, and time could be spared for trapping. They visited the trading post in their region at least once a year and usually a few families settled permanently at the post. When missions, police detachments, schools, and meteorological stations were established in the north, it was usually at the trading posts, which received supplies regularly and were already to some extent centres of population. As a result small settlements grew up, but their locations depended in the first instance solely on their suitability for the fur trade. Frequently this has resulted in no difficulty, but in other cases problems have developed with the growth of the settlements. For instance, most posts were established before there was any thought of aviation. In recent years the importance of aircraft has been emphasized as an auxiliary means of normal transportation, as a way of meeting emergencies caused by epidemics and accidents, and as a convenience for inspecting parties and scientists. A small northern community requires at least a place where float-equipped aircraft in summer and ski-equipped aircraft in winter can land. Larger communities need an area suitable for development as an all-weather strip. At some of the old settlements these cannot be found.

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There are many other problems which may result from the growth of a settlement. The water supply, sufficient for a few people, may prove too limited for a larger population, there may be few suitable building sites, or the disposal of sewage may be so difficult that there are serious public health problems. These problems may become so acute that the only real solution lies in moving the whole settlement to a better site. This is always a difficult decision to reach as growth is usually gradual, and less expensive measures can often be found to meet the immediate need. An example is Aklavik where a large settlement has grown in the past thirty years on a site that is thoroughly unsuitable. There is no possibility of developing an airfield at reasonable cost, the provision of adequate water supply and sewage disposal systems would be extremely expensive, conditions for construction are very bad, and there is no room for expansion. These conditions have forced a decision to move the whole settlement, but the move will be much more expensive than would have been the case if the decision had been made several years ago when the limitations of the site were first recognized.

It is extremely difficult to prevent the development of a situation such as that at Aklavik. Long-term planning by the various agencies concerned in the north can however indicate the areas where growth is likely, and additional activities should be centred on those settlements only which can be shown to be suitable for expansion. In recent years there have been a number of new settlements in the north arising out of the need for additional meteorological stations, or from mining activities. The importance of a careful choice of sites which will allow for future expansion as well as immediate needs, cannot be over-emphasized. Expert interpretation of air photographs is becoming increasingly useful in indicating the more suitable localities, but only a detailed ground survey including sampling of soil and sub-surface conditions by drilling can provide the full information required.

The development and settlement of the north will depend mainly on transportation and the mining industry. The location of mining communities will be restricted to the area of the minerals being exploited. In the case of base metals, transportation is so important a factor that exploitation in the near future can usually be expected only near to ports or to present, or easily developed, land transportation routes. There may of course be exceptions where resources are so important that the building of a whole transportation system is justified. An example is Knob Lake in Quebec where the high grade iron ore has resulted in the building of 360 miles of railway through practically uninhabited and frequently difficult country. In general, however, it seems likely that settlement will extend gradually into the north, as mineral development is made economically feasible by new transportation facilities. The mines will foster the growth of secondary industries and establish markets for local produce. This will encourage investigation of the possibilities of northern agriculture, fisheries, and the raising of livestock such as reindeer and possibly sheep.

In that part of the north too remote for economic mineral development in the near future, three main factors will affect settlement: transpolar aviation,

military activities, and administrative needs. With the increasing use of trans-polar aviation routes additional airfields and other supporting installations will be required. There will be development of a few major airfields, where terrain and meteorological conditions are suitable and supply by sea possible. A closer network of meteorological stations and aids to navigation will also be required. Military needs can be expected to result in some settlement while their logistic demands will assist in the establishment of communications and in this way accelerate the pace of economic development. In addition growing administrative services, such as schools and medical facilities for native peoples, will cause some expansion of certain settlements and a concentration of population around them. There is already a noticeable trend among the Eskimo towards larger groups and this will be accelerated by the high rate of natural increase of population shown by recent census figures, and by any success in promoting local industries.

Investigation of the problems of building research will make an important contribution to settlement in the north. Modern materials and techniques are already greatly simplifying construction problems and adding to human comfort, while permafrost research is leading to ways of avoiding the difficulties of providing suitable foundations, but much further work is required. New methods of heating, such as the possibilities of the heat pump, should be investigated. A start has been made in studying the accommodation requirements of Eskimo and the design of houses and methods of heating suited to their needs. More difficult is the establishment of a social life in isolated settlements acceptable to modern standards. This involves a wide field of social studies, including the relations between the native and white populations, the provision of adequate educational and cultural facilities, the development of responsible local government, and the fostering of interests to attract a permanent rather than a transient population. History shows that these problems can be solved by time. The Red River colony was considered by many to be in an area where no permanent settlement was possible and those who took part in the Cariboo Gold Rush packed their supplies through country which they regarded as unsuitable for agriculture and unthinkable for white women. Yet white women have succeeded in pushing their homes farther into the north whatever difficulties lay in the way. Today we should determine the problems that have been met in the past and learn how they may be solved in order to save time and prevent hardship.

Finally the role of government in the north needs constant review. There are a number of ways in which settlement can be encouraged. The value of investing in the future is recognized, but the amount that can be done in the north at any time must depend on what is desirable in relation to other demands on the economy of the country as a whole. Modification of fiscal policies, provision of subsidies and loans, increase of public services including transportation facilities and technical surveys are among the measures which can be taken to accelerate the rate of northern development, but which must be planned on sound research and knowledge of the problems.

Transportation

In most undeveloped regions travel is difficult and this has always been the case in the north. In general the needs of the very small population have not been sufficient to justify the heavy expense of building roads and railways. There have been exceptions when some particularly valuable resource has been discovered in a comparatively inaccessible area, and has resulted in construction of a new route across difficult country, as for example the discovery of gold in the Klondike which led to the building of the White Pass and Yukon Railway through the Coastal Range. In the same way urgent strategic considerations have sometimes demanded rapid development of communications, such as the Alaska Highway, the Crimson Staging Route airfields in northeast Canada and Greenland, and the Canol pipelines and road. The Mackenzie River route, however, illustrates well how the discovery and development of resources have been influenced by the existence of a natural transportation route. On this river and its associated waterways many of the valuable resources so far known in the Canadian north have been found: the Athabasca Tar Sands, the gold of Yellowknife, the uranium of Lake Athabasca and Great Bear Lake, the oil of Norman Wells and possibly higher up the Mackenzie, the base metals at Pine Point and the east arm of Great Slave Lake, and the fish of Great Slave Lake itself.

In the north therefore the transportation routes have usually preceded the discovery and development of resources. The current mining activities along the Alaska Highway are the result of the building of the route; the highway was not built to serve these activities, and it might be a more useful highway if potential resources had been considered when it was planned. There are many other examples where the development of communications in the northern parts of the Canadian provinces has resulted in the discovery of mineral riches, for instance the silver and cobalt on the Timiskaming and Northern Ontario Railway, the rich mining district of northern Ontario and the adjacent area of Quebec along the Grand Trunk Pacific, and the nickel-copper at Sudbury on the Canadian Pacific main line. The fundamental problem of transportation in the north today is how to plan the development of facilities to serve resources, rather than to build the facilities and then find the resources as in the past; it is in fact the well-known transportation problem of putting the horse before the cart.

The first need is for adequate maps, that is, maps showing sufficient detail and of sufficient accuracy for plotting information gained by surveys. All information on the known resources must then be gathered, and those areas determined where the prospects of discovering and developing resources are most promising.

For centuries the only important resources in the north were whales and fur. Whales were over-exploited and are not at present of any significance. The fur trade still continues but trapping is not compatible with settlement, and makes comparatively small demands on transportation. There are other

zoological resources and possible resources, fishing and reindeer herding for instance, and certain areas might be suitable for farming principally for local consumption. It is important to assess these potentialities, but there is little doubt that the main development in the north in the future will depend on the mineral and water power resources.

Unfortunately knowledge of the geology of much of the north is fragmentary. Detailed geological studies of such an enormous area can come only as a result of a sustained effort over very many years. It is possible, however, to carry out geological reconnaissance to determine the more favourable areas for prospecting much more rapidly. Of particular significance therefore is the 1952 Operation Keewatin of the Geological Survey of Canada in which the geology of an area of 57,000 square miles was determined in outline during a single season by a party with two helicopters. A similar operation, Operation Baker, was carried out in 1954 and further surveys of this sort are planned. Not only does this work direct prospecting to the more favourable areas, but it also provides information essential to the proper planning of transportation facilities, showing both the areas where transportation will most likely be required, and the eskers and other sources of engineering materials required in building facilities.

Only when much more has been found out about the resources of the north will it be possible to relate them to the main arteries into the north and to draw up a master plan for transportation construction to follow. The most promising areas should be provided with facilities for assisting detailed exploration and main routes should be planned to integrate the needs of different areas. As exploration proceeds, transportation requirements within the areas will become more definite and secondary routes can be determined. Without such a master plan, which must be constantly revised as fuller information is obtained, communication needs will be met piecemeal and some of the effort will be wasted. There is also always the possibility that military considerations will again require the construction of communications at short notice and these should, if at all possible, fit in with the master plan. In fact only in this way can the full military potentialities of the communications be realized, as the true military strength of a nation depends in large measure on the resources it controls. Similarly military needs, as far as they can be foreseen, should be considered in any plan to develop communications.

The development of a master plan based on potential resources as a guide for communications does not, of course, solve all transportation difficulties. It defines the scope of the problem, indicating the scale of facilities required and how construction should be phased, but there is still much to learn about the most satisfactory means of transportation in different conditions. The development of transportation facilities in the past and their effect on both long-term and short-term exploitation of natural resources and on the growth of secondary occupations should be examined in detail. The relative merits of railways, all-weather roads, winter roads, water transport, and air transport must be considered in each instance and the technical problems of all of these require study.

Many of these problems lie in the field of engineering. The work done since the Second World War on permafrost and its effect on construction is an example of the type of investigation that will provide valuable information. Research on northern construction and satisfactory fuels, lubricants, batteries, and rubber for low temperature operation will make important contributions. Snow surveys are required, as well as the development of satisfactory techniques for compacting and removing snow. Much can be done to design better oversnow vehicles and sledges. There are few soundings in northern waters and it will take many years to provide the detailed hydrographic surveys required for safe navigation. Satisfactory methods of reporting and forecasting ice conditions will be of great assistance to shipping. These are only a few of many instances where transportation will benefit from the continuous improvement that can be expected as a result of research and development. Owing to their military implications many of these subjects have received continuous attention during the past few years and the results of their work will help to solve civilian as well as military problems.

In addition to the internal communications required to develop resources, there is another aspect of transportation in the north which is becoming increasingly important. It is now many years since Vilhjalmur Stefansson and others first drew attention to the advantage of great circle flights across the Arctic. The British Arctic Air Route expedition led by Gino Watkins carried out pioneer investigations in Greenland and many notable flights were made in pre-war years, especially by the Russians. The great advances in aviation and navigation during and since the Second World War overcame many of the technical difficulties, and in the post-war years long-range military flights in the Arctic have become commonplace. The lack of adequate bases in the far north, the consequent restrictions on pay-loads, and the more exacting safety requirements, however, prevented commercial exploitation of the possibilities of transpolar flights.

With the opening by the U.S.A.F. of a major base at Thule the position has changed radically. In 1952 the Scandinavian Airlines System made two experimental flights from Los Angeles to Scandinavia via Edmonton and Thule, and in June 1953 the first commercial arctic flight from Oslo to Japan via Thule and Anchorage was successfully completed. In November 1954 the Scandinavian Airlines System instituted a regular service from Los Angeles to Scandinavia via Winnipeg and Søndrestrøm in Greenland, and Canadian Pacific Airlines has now begun a transpolar service from Vancouver to Amsterdam. During the next few years a number of additional commercial routes across the Arctic will probably be established, while under the bilateral air transport agreements with Canada the United Kingdom has for several years had the right to use Churchill on the route London–Prestwick–Keflavik–Goose Bay–Churchill–Alaska. To support civilian operations there will be a need for additional airfields and for increases in meteorological, navigation, and radio facilities. More research will be required, especially in such fields as the meteorology of the upper air in the north and the problems of navigation in high latitudes.

In planning the development of transportation, the interests and potentialities of the native population must not be neglected. Most interesting problems for research lie in the effect that these developments may have on the Eskimo and the part that they could play in maintaining and operating transportation facilities. Much of the north will long remain unattractive to white men, and there is a pressing need for additional sources of income for the Eskimo owing to the unprofitable condition of the fur trade, their only important economic support. If the Eskimo could take a major part in maintaining the transportation services of the north it would be of lasting benefit to them and would greatly assist the development of the north.

COLD ACCLIMATIZATION IN ESKIMO

G. Malcolm Brown*

On exposure to cold the body has a complicated physiological problem to solve. There is a limit to the heat it can produce to provide for an increased heat loss and during exposure of much severity a heat deficit is incurred. While peripheral tissues are cooling, the central body temperature must be kept within a very narrow range if the function of vital organs is to be maintained. If the accomplishment of this results in the failure to maintain a certain delivery of heat to the limbs, the usefulness of hands and feet is impaired. On the other hand if circulation to the extremities and to the surface of the trunk is greater than that required for necessary function, the heat loss is needlessly large and central body temperature is prejudiced. There is obviously room for subtle adjustment if vital needs are to be met and working capacity reasonably maintained in an economic fashion. It is the sum of the adjustments following repeated or prolonged exposure to cold which constitutes acclimatization to cold.

There has been doubt that acclimatization to cold exists in man. Many early experiments in the laboratory supported the view that it does not occur while observations in the field suggested that it does. The literature as a result is confusing. This is not surprising for the search for acclimatization had to begin before the nature of it was known. Often evidence was looked for in subjects thought to be acclimatized who actually were not. Another difficulty has been the selection of proper tests. The basis so far of all tests of acclimatization is a defined cold exposure and the observation of one or more physiological parameters. If the exposure is too severe, the test may be so indelicate that a real difference between subjects may not be apparent. Also, there has often been failure to recognize that there is in some respects a phasic response to continued exposure to cold. For instance, the blood volume is first reduced and then increased. It is, therefore, impossible to speak simply of the effects of cold. It is necessary to speak of the effects of one set of environmental conditions, temperature, air movement, humidity, and radiation, on subjects whose clothing is described and whose previous cold exposure is defined.

At a time when no physiological definition of acclimatization was available and it was not known how much exposure was required to achieve acclimatization, an attempt was made to get around the difficulty of finding fully

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acclimatized subjects by using Eskimo in the Canadian Eastern Arctic (Southampton Island) who were still carrying on their traditional hunting and trapping. Because of their performance in the cold it seemed safe to assume that these men were acclimatized though in the beginning uncertainty had to be admitted. It was also recognized that racial difference, experience in the technique of arctic living, dietary differences, and efficient clothing were factors which might have to be considered when data were interpreted. As it has turned out, the data on the Eskimo and data on Caucasians who have been subjected to cold over a really long period have together justified the choice of Eskimo as experimental subjects, and at present they are the group who have been studied most intensively.

Cardiovascular system

Vascular dynamics between acute cold exposures

Studies on Eskimo reclining comfortably in a room at 20°C and dressed in the same clothes as a control group of unacclimatized white men have shown differences in the pattern of the peripheral circulation and in cardiac action. They have a slower pulse rate than the control group and they also have a lower blood pressure (Brown, 1955). The latter has been remarked on by Høygaard (1941). The volume of blood flowing through their hands and forearms has been measured plethysmographically and it is about 75 per cent greater than that of the unacclimatized group (Brown and Page, 1952; Brown *et al.*, 1953). Skin temperatures recorded by thermocouples from twelve points on the trunk, arm, and leg show that the trunk, the shoulder, and the calf of the leg are kept at a higher temperature. The thigh and the great toe show no differences and the hand and forearm are significantly lower. Muscle temperatures have been measured with needle thermocouples and the muscles of the forearm, the thigh, and the calf are distinctly cooler in the Eskimo (Brown *et al.*, 1955). If the forearm and hand are covered with cotton wool, the hand skin temperature and the forearm muscle temperature are the same in the acclimatized and the unacclimatized and the forearm skin temperature becomes a little higher in the Eskimo. If more insulation is provided, as with a plethysmograph, both the hand and the forearm become warmer than in the controls and the forearm muscle temperature also rises. There is no difference in rectal temperature under these conditions. In summary, the Eskimo while maintaining the same rectal temperature as unacclimatized white men in the conditions specified have warmer skin over the trunk and the proximal parts of the limbs, cooler hands and forearms, and lower muscle temperatures in the limbs. The hands and forearms, however, are warmer in the Eskimo when a moderate covering is provided.

Few data have been obtained on acclimatized or partially acclimatized white men in the intervals between test exposures. Carlson *et al.* (1951) indicate in one of their diagrams that they found the hand temperature was higher in the acclimatized. More extensive data are provided by Balke *et al.* (1944) who recorded skin temperatures of men who lived for four weeks in

February in an unheated tent on a mountainside in the Tyrol. The air temperature seldom fell below -10°C and the men were dressed in army uniform and parka. Skin temperatures were recorded before bedtime and in the morning before getting up. Tabulation of the data presented in published graphs shows that there was a fall in the temperature of the abdomen, back, knee, and toe. If the records of the last five days are compared with those of the first five, the fall in temperature can be shown to be about the same at all four points. This work is not completely comparable with the work on the Eskimo. The basal metabolic rate of the subjects did not increase during the four weeks so that they cannot be considered acclimatized to the same degree as the Eskimo (*see* below). Also, the observations were in a sense made during the cold exposure. The men were comfortable in their tent in their heavy clothing but their faces were of course exposed. (The effect of cooling the face on peripheral vasodilatation is not known but Macht and Bader (1948) showed that at low ambient temperatures warming the face is more effective in increasing blood flow than is warming of other areas).

Vascular response to acute exposure

The vascular response of the Eskimo to acute cold exposure has also been shown to be different from that of unacclimatized white men. When the test exposure is the immersion of the right hand and arm in a 5°C water bath, the pulse rate remains slower in the Eskimo but the blood pressure reaches a higher level and it is maintained there during the 1-hour test (Brown, 1955). This could be due to greater cardiac output or to increased peripheral vasoconstriction in the Eskimo. Cardiac output has not been measured but there is good evidence of greater peripheral vasoconstriction. The reduction in blood flow through the hand and forearm is greater in the Eskimo though at all times during the test they maintained a greater blood flow than the controls. Despite the greater blood flow through the forearm, the forearm muscle temperature falls faster and farther in the Eskimo (Brown and Page, 1952; Brown *et al.*, 1953). This greater loss of heat from the forearm is to be explained by the greater flow of blood through the hand and hence the return through the deep veins of the forearm of a greater volume of cooled blood.

It has been seen that in the resting state the Eskimo have higher skin temperatures over the trunk and the proximal parts of the limbs and cooler hands and forearms than the controls. During the test exposure roughly the same profile of skin temperatures is maintained and the muscle temperatures remain lower than in the unacclimatized but there are significant differences of degree in the changes which occur. The average trunk temperature rises in both groups but more in the Eskimo. Skin temperature on the thigh and all muscle temperatures in the limbs fall farther in the unacclimatized. Rectal temperature is better maintained by the Eskimo during the test and the original level is regained within 30 minutes of its termination whereas the rectal temperature of the unacclimatized continues to fall significantly during the recovery period. Continued significant drops in temperature during the

recovery period are seen in the unacclimatized on the forearm, hand, and in the muscles of the calf and forearm. In the Eskimo temperatures are maintained or even raised during the recovery period except over the forearm and hand (Brown *et al.*, 1955). It seems, therefore, that in meeting the stress of a moderately severe cold exposure the acclimatized Eskimo has an enhanced ability to maintain both central body temperatures and blood flow to the limbs.

Similarly increased resistance to cold has been repeatedly observed in white men when their previous cold experience has been sufficiently prolonged or intense. Horvath *et al.* (1947) exposed soldiers dressed in arctic suits to -29°C for eight days and found that the thigh temperature was better maintained in the later days of the experiment. Ames *et al.* (1948) placed men dressed in arctic clothing in a room at -40°C for sixteen 2-hour periods in the course of three weeks and found that shivering began later and that toe temperatures were better maintained in the later exposures. Glaser (1949) had men dressed in woollen underwear, shirt, trousers, and jacket spend two 72-hour periods in a room at -1 to -4°C with an intermediate interval of 72 hours in a hot room and he found that the second cold exposure was subjectively better tolerated than the first and that on the last day of the cold exposure the skin and rectal temperatures rose slightly. It is interesting that objective evidence of adjustment was found after such a short exposure. Carlson *et al.* (1951) reported increased blood flow in the fingers in men who had been in the Arctic for some months and were considered acclimatized. In later experiments he found that after daily exposure to the arctic winter for 16 to 18 hours for fourteen days there was a slower initial drop in hand temperature with maintenance at a higher temperature throughout the test exposure. He also found that there were increased differences between the temperatures of the rectum and the arm muscle, between rectum and leg muscle, and between the skin and muscle of the arm. At the end of the experiment removal of the jacket caused a smaller drop in hand temperature than it did at the beginning (Carlson *et al.*, 1953). As can be seen, practically all these studies have been done on subjects whose period of acclimatization has been quite short. What is still required is a study on white men who have been exposed to the cold for very much longer periods.

Carlson *et al.* (1951, 1952, 1953) formulated an hypothesis concerning acclimatization to cold which has excited the interest of all workers in the field. "This hypothesis states that on exposure a readjustment in circulation occurs which leads to warmer extremities and cooler body surface, and which tends to increase the effective body weight acting as shell" (1952, p. 22). According to this concept the shell is that part of the body which gives up its heat on exposure of that part or of some distant part of the body to cold. It has been Carlson's view that the contribution made by the shell is important and that it is greater in the acclimatized. There are several arguments which suggest that this may not be the case. Since the central body temperature, or core temperature, does not rise on exposure to cold except for very short periods, and since the temperature of the extremities falls, the contribution made by the shell must be part of the heat deficit incurred during a moderate

or severe cold exposure. Horvath *et al.* (1947) found in men exposed for one hour in arctic clothing to very low temperatures that the heat deficit was incurred during the first ten minutes. After this period the stress must be met by heat from other sources than the shell. As has been seen, the trunk skin temperatures in the Eskimo do not indicate a cooler body surface as postulated by Carlson. Increased heat loss from the forearm muscles was noted in the arm placed in the cold water bath but in the other arm the drop in muscle temperature was significantly less in the Eskimo and a similar situation existed in the thigh and the calf. These regions do not, therefore, under the conditions of the experiment behave as part of the shell, which is at variance with Carlson's findings under admittedly different experimental conditions. Another possible point of difference is found in the extremities. In the hand directly exposed to the cold in the Eskimo experiments, the blood flow was always higher than it was in the control group. This was also the case when the legs were cooled, but when the hand was left uncovered at room temperature it was cooler in the Eskimo than it was in the control group. Finally, Carlson *et al.* (1951, 1953) postulated that metabolism supplies less of the total heat lost during acute exposure of the acclimatized person. The evidence available on oxygen consumption in the Eskimo is against this (*see* below) and Carlson's own work with animals has led him to reconsider his original suggestion which was based on studies on man (Carlson, 1955).

Metabolism

Basal metabolic rate

During cold exposure it is well known that heat production is increased but the full mechanism of this is still obscure. Increased activity of the thyroid has been suspected to be one of the contributing factors but the view that it occurs in man has often been questioned. In the Eskimo used in the present studies, the basal metabolic rate (B.M.R.) has been found elevated during the summer months (Brown *et al.*, 1954a). Unfortunately winter-time observations have not been made. Considerable care was taken to get readings under basal conditions and the subjects were as a result studied between 4.30 and 9.30 a.m. while still in their own beds. Usually the subjects were quieter and more at ease than are patients in routine hospital work. Determinations were made at fortnightly intervals between 11 July and 29 August 1949 and the average B.M.R. was 31.5 per cent, 27.6 per cent, 26.7 per cent, and 23.8 per cent above normal (Boothy and Sandford) on the four occasions. The fall during the summer is statistically significant.

The literature contains greatly varying reports of the B.M.R. in different groups of Eskimo. Levine (1937, 1939, 1949) in Alaska, Heinbecker (1931) at Pangnirtung, and Rodahl (1952) in Alaska reported that they found a normal average B.M.R. Rabinowitch and Smith (1936) working from a ship delivering supplies in the Canadian Eastern Arctic, Crile and Quiring (1939) at Chesterfield Inlet, Høygaard (1941) in east Greenland, Bollerud *et al.*, (1950) in Alaska, Heinbecker (1928) at Cape Dorset, and Rodahl (1952) in

some of his subjects in Alaska found an abnormally high B.M.R. Examination of the reports shows that the B.M.R. is elevated in those Eskimo who are still adhering in an important way to their own culture but there have been many suggestions that the apparent elevation is false. Anaemia or unidentified disease (Levine, 1951), polycythaemia (Rabinowitch and Smith, 1936), racial characteristics (Gottschalk and Riggs, 1952), and a high protein diet (Heinbecker, 1931; Rodahl, 1952; Carlson *et al.*, 1953) have been suggested as causes of error. With care and proper clinical study of the subjects selected for testing, anaemia and other disease can be excluded. It is doubtful if racial origin is a factor, for an elevated B.M.R. is found in those of known mixed blood as well as in apparently full-blooded Eskimo. Neither is it likely that a high protein intake is responsible. McClellan *et al.* (1931) fed two men for twelve months a diet composed exclusively of meat and fat and reported only a slight and transient elevation of B.M.R. It is probable that an Eskimo group taking a high protein diet is a group still largely living the traditional native life, and that a group using a low protein diet is using important amounts of white man's food and very probably imitating him in other ways so that their cold exposure is reduced. This interpretation of the discrepancies in the estimates of B.M.R. in the Eskimo can also be applied to the work of Gottschalk and Riggs (1952) who found that the average serum protein-bound iodine was higher in the subjects studied at Southampton Island than it was at Chesterfield Inlet. The results of the assessment of thyroid activity, both by measurement of oxygen consumption and by determination of serum protein-bound iodine, indicate that any attempt to generalize about the Eskimo is mistaken and that the characteristics and conditions of life of the group studied must to some extent be defined if experimental results of any type are to be interpreted correctly.

There is similar variability in the reports on the B.M.R. of white men exposed to the cold. Balke *et al.* (1944) found no change in B.M.R. in their subjects and Ames and Goldthwait (1948) found no significant change in ten technicians during a three-month winter stay at Churchill, though their eleventh subject, a truck driver who spent considerable time out-of-doors, showed an increase of 30 per cent. Newburgh and Spealman (1943), on the other hand, reported that the B.M.R. in lightly clad men living in a room at 15°C increased after about ten days, and Horvath *et al.* (1947) found an increase in resting oxygen consumption after eight days in men dressed in arctic clothing and living at -29°C.

It seems reasonable to conclude that the apparently contradictory results of different workers are to be explained by the various durations and severities of the cold exposure involved and that when the exposure is long enough and severe enough an elevation of B.M.R. occurs. This is in line with extensive laboratory experiments with the rat (Ring, 1942) and the rabbit (Lee, 1942).

Metabolism during acute exposure

Oxygen consumption has been measured in a small group of Eskimo during the same test exposure as used in the other studies. The difference between

the change in their oxygen consumption and that of the control group during exposure is not statistically significant, but there was a continued rise in oxygen consumption of the control group during the recovery period which suggests that they accumulated a greater heat deficit during the hour of exposure (Brown *et al.*, 1955). If this is so, the Eskimo met the heat loss to a greater extent by increased muscle activity or by increased visceral metabolic activity. If they are like acclimatized rats there is a greater increase in visceral metabolic activity than in muscle activity (Sellers *et al.*, 1954).

These data on oxygen consumption are not in agreement with the similarly scanty data available on white men. When Balke *et al.* (1944) brought their men down from the mountain and placed them in a 20°C bath for twenty minutes, they found the oxygen consumption during this exposure to be the same as it was before the four-week bivouac. Carlson *et al.* (1951) concluded that during a 1-hour exposure in an experimental suit to temperatures -8° to -32°C the metabolic rate increased less in the acclimatized than in the unacclimatized. It has already been pointed out that he is reconsidering the significance of this part of the results of those experiments.

If there is confirmation of the lesser oxygen consumption by the Eskimo during the combined exposure and recovery period, more evidence will be provided of the greater lability of the means of heat production or control which they appear to possess. Other evidence of this capacity was provided in the experiments in which blood flow and tissue temperatures were studied in the arms while the legs were heated or cooled and it is interesting that it was also observed in the warming experiments (Page and Brown, 1953). This seems in contradiction to the Eskimo's subjective reactions but these are the result of many factors.

Blood volume

Since the reports of Bazett and his colleagues (Sunderman *et al.*, 1939; Bazett *et al.*, 1940) that in white men in Philadelphia there was an increase in blood volume in the summer and a decrease during the winter, it has been the commonly held view that chronic exposure to cold causes a decrease in blood volume. There was support in the work of Spealman *et al.* (1947). It was as a result something of a surprise in 1950 to find in the Eskimo on Southampton Island a markedly elevated plasma volume (Brown *et al.*, 1954b). The average plasma volume about the middle of July was over 40 per cent above the accepted average normal and well outside the accepted normal range. During the summer the plasma volume fell but not to normal levels. The total red cell volume was also increased, though to lesser extent than the plasma volume and the fall during the summer was not as great. The elevation of plasma and total red cell volume has been recently confirmed but the fall during the summer was not studied again (Brown *et al.*, 1955).

It is probably the case that this is another of the apparent contradictions which are to be explained by difference in the previous cold exposure of the subjects. There is support for the view in this particular instance in the literature on white men. Conley and Nickerson (1945) reported that the

reduction in plasma volume which occurred at the beginning of cold exposure was temporary and that the plasma volume had practically returned to normal after a few days. The reduction of plasma volume and the diuresis which occur on acute exposure are well known. It may well be that a slight exposure repeated over many months has only this type of effect and that a much more severe and continued exposure is required before the plasma volume not only returns to normal as Conley and Nickerson observed, but goes on to be increased. This, actually, is my view. It is consistent with the pattern of blood flow and skin and tissue temperatures which have been found in the Eskimo. It is also consistent with the elevations of B.M.R. and serum protein-bound iodine which have been found, for there is a roughly linear correlation between B.M.R. and plasma volume in the untreated hyperthyroid state (Gibson and Harris, 1939). The increase in plasma volume found in the Eskimo is of the same order as that reported in a series of cases of hyperthyroidism in which the average B.M.R. was +41 per cent (Goldbloom and Libin, 1935).

The elevation of blood volume found in the resting and fasting state led to investigation of the changes during the test exposure of placing the right hand and forearm in a 5°C water bath for one hour. Twenty minutes after the immersion the average Eskimo plasma volume was found to be decreased by 9 per cent, and in absolute terms this change was 30 per cent greater than that seen in the controls. Haematocrit determinations suggested that there was a further fall in the Eskimo and that there was a more rapid return to normal during the recovery period. An important point was that the urine output was the same in the two groups. The demonstration of a diminished plasma volume on acute cold exposure is not new but a difference between acclimatized and unacclimatized is, and the absence of diuresis of different size may mean that the initial phase of contraction of plasma volume is not to be explained simply by increased water excretion by the kidneys. The greater contraction of plasma volume in the acclimatized is consistent with the greater peripheral vasoconstriction and the pattern of changes in skin and tissue temperature seen in this group (Brown *et al.*, 1954b).

Ascorbic acid

Many interesting points have been noted in the blood and urine chemistry of the Eskimo. They include a low creatinine excretion, low urinary sulphate/nitrogen ratios, surprisingly low plasma lipids, high serum electrolyte/urinary electrolyte ratio, and a low plasma ascorbic acid/urinary ascorbic acid ratio (Brown, 1955). All these may be the result of dietary factors but the ascorbic acid findings deserve mention because of some experiments with white men. LeBlanc and Marier (1950, personal communication) found that in troops on a winter-time arctic exercise the urinary excretion of ascorbic acid was greater than it had been in the preliminary control period. LeBlanc *et al.* (1954) have also reported that the supplementing of survival rations (550 calories per day) with ascorbic acid 525 mg. per day was followed by an increase in average skin temperature and a decrease in the discomfort due

to cold. In the Eskimo the average concentration of ascorbic acid in whole blood, plasma, and leucocytes has been found to be low, as might be expected, but the amount excreted in the urine was very much greater than in unacclimatized white subjects. In a loading experiment this was the case in both groups at two levels of plasma ascorbic acid. It may very well be, however, that this is due to a high intake of other nutrients and that it is not an effect of cold (Brown, 1955).

The concept of acclimatization which has arisen out of the work on Eskimo has as some of its features increased lability of the means of heat production or control, hyperactivity of the thyroid, increase in circulating blood volume, warmer skin over the trunk and proximal parts of the limbs, increased blood flow to the extremities, and better maintenance of skin and tissue temperatures during acute exposure. Before the validity of this concept is fully established, similar physiological changes must be demonstrated in white men and to accomplish this it will be necessary to plan more strenuous and prolonged experiments than any so far carried out. In new experiments many factors still unknown can be studied. The speed with which various degrees of cold acclimatization are acquired or lost is just hinted at in present experimental data. The order in which various features appear in different circumstances is not known. It may be different when the process of acclimatization is short but severe rather than long and less strenuous. There may also be differences when the face and extremities are chiefly exposed rather than the trunk. The importance in man of possible changes in the insulation provided by adipose tissue is not known.

It is possible that the degree of acclimatization seen in the Eskimo is not really important for any purposes but theirs. For the rest of us, lavish equipment, attention to the technique of arctic living, and simply more men may compensate for physiological inefficiency. If the only goal of work on cold acclimatization is the increase of the functional capacity of white men in the Arctic, it may be a relatively unprofitable field of endeavour.

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Anthropology and Ethnology

Edmund S. Carpenter, Dept. of Anthropology, University of Toronto, Toronto, Ontario, Canada.	Archaeological, geological, and ethnological investigations at Southampton Island, Northwest Territories. Initiated: 1950—Completion: Spring 1952.
Philip Drucker, Bureau of American Ethnology, Smithsonian Institution, Washington, D.C., U.S.A.	Modern inter-tribal organization in northern British Columbia and southeastern Alaska. Initiated: 1953—Completion: 1955.
Louis L. Hammerich, University of Copenhagen, Frue Plads, Copenhagen, Denmark.	A study of the language of the Nuniwagamiut Eskimo, at Nunivak Island, Alaska. Initiated: 1950—Completion: Spring 1953.
Louis L. Hammerich, University of Copenhagen, Frue Plads, Copenhagen, Denmark.	A study of the Eskimo of southwestern Alaska, especially with respect to dialectic frontiers between the Eskimo and the Aleuts. Initiated: 1953—Completion: 1955.
Frederica de Laguna, Bryn Mawr College, Bryn Mawr, Pennsylvania, U.S.A.	An ethnological-archaeological study of the development of Tlingit culture in southeastern Alaska. Initiated: 1949, 1950—Completion: Spring 1952.
Frederica de Laguna, Bryn Mawr College, Bryn Mawr, Pennsylvania, U.S.A.	Continuation of combined ethnographical and archaeological investigations at Yakutat, Alaska. Initiated: 1953—Completion: 1955.
Margaret Lantis, The Grant Study, Harvard University, Cambridge, Massachusetts, U.S.A.	An ethnographic study of the Eskimo of Nunivak Island, Alaska. Initiated: 1946—Completion: 1952.
Helge Larsen, Etnografisk Samling, Nationalmuseet, 10 Ny Vestergade, Copenhagen, Denmark.	A study of the ethnological and physical anthropology of Eskimo in the region between Norton Sound and the Alaska Peninsula. Initiated: 1948—Completion: Spring 1952.
William S. Laughlin, Dept. of Anthropology, University of Oregon, Eugene, Oregon, U.S.A.	A study of Aleut and pre-Aleut archaeology, ethnology, and physical anthropology (Aleutian Islands). Initiated: 1949—Completion: Autumn 1951.
William S. Laughlin, Dept. of Anthropology, University of Oregon, Eugene, Oregon, U.S.A.	Aleutian anthropology. Initiated: Summer 1952—Completion: 1955.
Charles Vincent Lucier, University of Alaska, College, Alaska.	Studies of the non-material culture of the Noatak Eskimo. Initiated: Summer 1952—Completion: 1955.
Edward S. Rogers, Dept. of Anthropology, University of New Mexico, Albuquerque, New Mexico, U.S.A.	Linguistic and ethnographical study of the Mistassini Indians of northern Quebec. Initiated: 1953—Completion: 1955.
Richard D. Slobodin, Los Angeles State College of Applied Arts and Sciences, Los Angeles 27, California, U.S.A.	An ethnological study of the Peel River Kutchin in the vicinity of Ft. McPherson, Northwest Territories. Initiated: 1947—Completion: Spring 1952.

PHILIP T. SPAULDING, Dept. of Anthropology, University of Oregon, Eugene, Oregon, U.S.A.	Anthropological and linguistic investigations in the Aleutian Islands. Initiated: 1953—Completion: 1955.
ROBERT F. SPENCER, Dept. of Anthropology, University of Minnesota, Minneapolis, Minnesota, U.S.A.	The human ecology of the Arctic Slope of Alaska. Initiated: 1953—Completion: 1955.
D. E. WILKINSON, 14 Catharine Street, Port Colborne, Ontario, Canada.	An experiment in social science among the Tununermiut Eskimo of north Baffin Island. Initiated: 1953—Completion: 1955.

Archaeology

JOHN OTIS BREW, Peabody Museum, Harvard University, Cambridge, Massachusetts, U.S.A.	An archaeological survey of Eskimo, or earlier, material in the vicinity of Point Barrow, Alaska. Initiated: 1953—Completion: 1955.
J. L. GIDDINGS, JR., The University Museum, University of Pennsylvania, Philadelphia 4, Pennsylvania, U.S.A.	The extension of the tree-ring chronology in Alaska by further excavation so as to date the early phases of Eskimo culture in the Bering Strait region. Initiated: 1948, 1949—Completion: Spring 1952.
ELMER HARP, JR., Dartmouth College Museum, Hanover, New Hampshire, U.S.A.	An archaeological reconnaissance along the west coast of Newfoundland with a view to elucidating the prehistoric cultures of Newfoundland. Initiated: 1949, 1950—Completion: Spring 1952.
WILLIAM IRVING, University of Alaska, College, Alaska.	An archaeological reconnaissance of the Brooks Range, Alaska, with the view to locating archaeological sites containing implements of the Denbigh Flint Complex. Initiated: 1951—Completion: Spring 1953.
L. A. LEARMONTH, P.O. Box 283, South Main Street, Georgetown, Ontario, Canada.	An archaeological reconnaissance of the King William Island-Boothia Peninsula region, Northwest Territories. Initiated: 1950—Completion: 1952.
DERIC O'BRYAN, Arctic, Desert and Tropic Information Center, Research Studies Institute, Maxwell Air Force Base, Alabama, U.S.A.	An archaeological study of Mill Island, Hudson Strait, including detailed excavation of a pure Cape Dorset Eskimo house site. Initiated: 1951—Completion: Spring 1953.
WENDELL H. OSWALT, University of Alaska, College, Alaska.	An archaeological survey from the south mouth of the Yukon River, Alaska, to Hazen Bay, with the excavation of the most promising site located by this survey. Initiated: 1950—Completion: Spring 1952.
JAMES W. VAN STONE, Dept. of Anthropology, University of Alaska, College, Alaska.	Archaeological reconnaissance of Nunivak Island. Initiated: Summer 1952—Completion: 1955.

Botany

CHESTER A. ARNOLD, Dept. of Botany, University of Michigan, Ann Arbor, Michigan, U.S.A.	Paleobotanical investigations in northern Alaska. Initiated: 1953—Completion: 1955.
LYMAN D. BENSON, Dept. of Botany, Pomona College, Claremont, California, U.S.A.	Field population studies of *Ranunculus* species occurring in northern Alaska. Initiated: 1950—Completion: Spring 1953.
WILLIAM S. COOPER and LLOYD A. SPETZMAN, Dept. of Botany, University of Minnesota, Minneapolis, Minnesota, U.S.A.	Botanical investigations of parts of the Brooks Range and Arctic Slope of Alaska. Initiated: 1948, 1949—Completion: Summer 1951.

HANNAH T. CROASDALE, Dept. of Zoology, Dartmouth College, Hanover, New Hampshire, U.S.A.	An ecological study of freshwater algae of arctic and subarctic Alaska, with particular reference to a comparison of glaciated and non-glaciated localities. Initiated: 1951—Completion: Spring 1953.
OLAF GJAEREVOLL, The Museum, Trondheim, Norway.	A floristic and phytosociological investigation of the White Mountains, Alaska. Initiated: 1953—Completion: 1955.
FELIX G. GUSTAFSON, Dept. of Botany, University of Michigan, Ann Arbor, Michigan, U.S.A.	A laboratory analysis of representative plants from the vicinity of Point Barrow, Alaska, with the view to determining their content of vitamins, including ascorbic acid, thiamine, riboflavin, and niacin. Initiated: 1951—Completion: Spring 1953.
HENRY PAUL HANSEN, Oregon State College, Corvallis, Oregon, U.S.A.	Pollen analysis of peat sections along the Alaska Highway. Initiated: 1950—Completion: Spring 1952.
HENRY PAUL HANSEN, Oregon State College, Corvallis, Oregon, U.S.A.	Pleistocene and postglacial forests in Alaska and western Canada. Initiated: 1952—Completion: 1955.
HERBERT C. HANSON, Biology Dept., Catholic University of America, Washington 17, D.C., U.S.A.	A study of the ecology and values of the principal grassland types of Alaska. Initiated: 1949—Completion: Spring 1951.
CALVIN J. HEUSSER, American Geographical Society, Broadway at 156th Street, New York 32, New York, U.S.A.	Pollen profiles from muskeg deposits in the Queen Charlotte Islands, B.C. and in the Olympic Mountains, Washington. Initiated: 1955—Completion: 1957.
ILMARI HUSTICH, University of Helsinki, Helsinki, Finland.	A forest-botanical survey of parts of the Labrador Peninsula. Initiated: 1947—Completion: Spring 1950.
LOUIS H. JORDAL, Dept. of Botany, University of Michigan, Ann Arbor, Michigan, U.S.A.	A floristic, phytogeographical, and ecological survey of the vegetation of the Brooks Range, arctic Alaska. Initiated: 1950—Completion: Autumn 1951.
DONALD B. LAWRENCE, Dept. of Botany, University of Minnesota, Minneapolis, Minnesota, U.S.A.	A study of the recent glacier history of Glacier Bay, Alaska, and of the development of vegetation on deglaciated terrain, with special reference to the importance of alder in the succession. Initiated: 1950—Completion: Spring 1952.
ERNEST LEPAGE, Ecole d'Agriculture, Rimouski, Quebec, Canada.	Botanical researches in James Bay. Initiated: 1952—Completion: 1955.
ERNEST LEPAGE, Ecole d'Agriculture, Rimouski, Quebec, Canada.	Completion of an inventory of the flora of the west coast of James Bay. Initiated: 1953—Completion: 1955.
GEORGE A. LLANO, 200 Prairie Vista, Montgomery, Alabama, U.S.A.	A study of the cryptogamic botany of the Arctic Slope of Alaska. Initiated: 1949—Completion: 1951.
J. W. MARR, Dept. of Biology, University of Colorado, Boulder, Colorado, U.S.A.	An ecological study of the Transition Zone between forest and tundra in northern Quebec. Initiated: 1948—Completion: Spring 1951.
DAVID ROSS MOIR, Dept. of Botany, University of Minnesota, Minneapolis, Minnesota, U.S.A.	A floristic survey of northwestern Ontario. Initiated: 1952—Completion: 1955.
DAVID ROSS MOIR, Dept. of Botany, North Dakota Agriculture College, Fargo, North Dakota, U.S.A.	Continuation of a floristic survey of northwestern Ontario. Initiated: 1953—Completion: 1955.

NICHOLAS POLUNIN, Dept. of Botany, McGill University, Montreal, Quebec, Canada.	A study of the flora and vegetation of the Canadian Eastern Arctic and Subarctic. Initiated: 1946—Completion: 1950.
JACQUES ROUSSEAU, Montreal Botanical Garden, Montreal, Quebec, Canada.	A botanical survey of the Labrador Peninsula between the head of Romaine River and Ungava Bay. Initiated: 1947—Completion: 1949.
JACQUES ROUSSEAU, Montreal Botanical Garden, Montreal, Quebec, Canada.	A botanical survey of Ungava–Labrador between the mouth of the Korok River and the Torngat Mountains. Initiated: 1951—Completion: Spring 1953.
ROYAL E. SHANKS, University of Tennessee, Knoxville, Tennessee, U.S.A.	An investigation of the composition, structure, and productivity of the tundra vegetation of northern Alaska, in the vicinity of Point Barrow. Initiated: 1955—Completion: 1957.
WILLIAM C. STEERE, Dept. of Biological Sciences, Stanford University, Stanford, California, U.S.A.	An investigation of the geographical distribution of mosses and liverworts (Bryophyta) in arctic Alaska. Initiated: 1953—Completion: 1955.
WILLIAM C. STEERE, Dept. of Biological Sciences, Stanford University, Stanford, California, U.S.A.	Conclusions derived from consultation with specialists and investigations of specimens in European institutions, in direct connection with bryological problems arising from arctic field work. Initiated: 1954—Completion: 1956.
J. W. THOMSON, JR., Dept. of Botany, University of Wisconsin, Madison, Wisconsin, U.S.A.	A study of the lichens of the west coast of Hudson Bay, their ecology, distribution, and abundance. Initiated: 1950—Completion: Spring 1952.
RISTO K. TUOMIKOSKI, Botanical Institute, University of Helsinki, Helsinki, Finland.	A floristic and ecological exploration of the Bryophyta of Newfoundland. Initiated: 1949—Completion: Spring 1952.
IRA L. WIGGINS, Natural History Museum, Stanford University, Stanford, California, U.S.A.	A comparison of collections made in arctic Alaska with authentic specimens in U.S. herbaria and completion of an account of the systematics and ecology of the seed plants occurring in Petroleum Reserve No. 4. Initiated: 1954—Completion: 1956.

Ecology

WILLIAM L. BOYD, University of Georgia, Athens, Georgia, U.S.A.	An ecological and taxonomic survey of microorganisms, under winter and summer conditions, in the vicinity of Point Barrow, Alaska. Initiated: 1955—Completion: 1957.
ALBERT M. DAY, Washington, D.C., U.S.A.	A study of the programs and policies of all land and water use agencies which affect the breeding, protection, and perpetuation of migratory waterfowl in North America. Initiated: 1955—Completion: 1957.
RODGERS D. HAMILTON, Museum of Zoology, University of Michigan, Ann Arbor, Michigan, U.S.A.	A study of the ecology of *Rana Sylvatica* in relation to permafrost, season, foods, and adaptations. Initiated: 1948, 1949—(Dr. Hamilton disappeared while on a flight in the field, spring of 1950).
FRANCIS HARPER, R.F.D. No. 1, Mt. Holly, New Jersey, U.S.A.	A biological investigation of the Nueltin Lake area in Keewatin and Manitoba, with special emphasis on the life histories and ecology of mammals, birds, and fishes, and on the distribution of plants. Initiated: 1947—Completion: Spring 1950.

FRANCIS HARPER, R.F.D. No. 1, Mt. Holly, New Jersey, U.S.A.	A comprehensive investigation of the animal and plant resources of the Knob Lake region, Labrador. Initiated: 1954—Completion: 1955.
DALE J. OSBORN, Dept. of Zoology, McGill University, Montreal, Quebec, Canada.	An ecological and distributional study of vertebrates and invertebrates of Ungava–Labrador. Initiated: 1951—Completion: Spring 1953.
G. CARLETON RAY, Dept. of Zoology, Columbia University, Palisades, New York, U.S.A.	Environmental zoological investigations in the vicinity of Juneau, Alaska. Initiated: 1954—Completion: 1956.
G. CARLETON RAY, Dept. of Zoology, Rutgers University, New Brunswick, New Jersey, U.S.A.	Continued environmental zoological investigations in the vicinity of Juneau, Alaska. Initiated: 1955—Completion: 1957.
LEONARD W. WING, Agricultural and Mechanical College of Texas, College Station, Texas, U.S.A.	Some phases of the relation of selected faunae population (avian and mammalian) in reference to weather at Kluane Lake, Yukon Territory. Initiated: 1948—Completion: Spring 1950.

Geography

T. E. ARMSTRONG, Scott Polar Research Institute, Cambridge, England.	A study of the geographical and economic development of the Russian Northern Sea Route. Initiated: 1948—Completion: Spring 1951.
G. VIBERT DOUGLAS, Dept. of Geology, Dalhousie University, Halifax, Nova Scotia, Canada.	A study of the terrain of the Labrador Peninsula including the coast of Labrador from Blanc Sablon to Cape Chidley and a description of the settlements along this coast. Initiated: 1947—Completion: 1949.
BARBARA J. HAWN, Dept. of Natural Resources, Oregon State College, Corvallis, Oregon, U.S.A.	A survey of the historical geography of tin on the Lost River, Seward Peninsula, Alaska. Initiated: 1955—Completion: 1957.
TREVOR LLOYD, Dept. of Geography, Dartmouth College, Hanover, New Hampshire, U.S.A.	Greenland—a survey of administrative developments and their relation to the geography of the region. Initiated: 1951—Completion: Spring 1954.
T. H. MANNING, 37 Linden Terrace, Ottawa, Ontario, Canada.	A geographical study of the coast of Hudson Bay. Initiated: 1947—Completion: 1950.
T. T. PATERSON, 6 Park Terrace, Cambridge, England.	A study of the terrain of the Canadian Eastern Arctic (exclusive of Labrador Peninsula). Initiated: 1947—Completion: Spring 1952.
DEMITRI B. SHIMKIN, Russian Research Center, Harvard University, Cambridge, Massachusetts, U.S.A.	A study of the economic geography of the Bering Sea coast and lower Yukon Valley of Alaska with a view to correlating patterns of development in comparable regions of the American and Soviet Arctic. Initiated: 1949—Completion: 1952.
JOSEPH SONNENFELD, Bowman Dept. of Geography, The Johns Hopkins University, Baltimore, Maryland, U.S.A.	Changes in subsistence economy among Point Barrow Eskimo. Initiated: 1954—Completion: 1956.
KIRK H. STONE, Dept. of Geography, University of Wisconsin, Madison, Wisconsin, U.S.A.	A geographical-geological study of Lake George and other ice-dammed lakes of Alaska, with the view to determining their physical characteristics and cultural significance. Initiated: 1951—Completion: Spring 1953.
JOHN J. TEAL, JR., 55 Otter Rock Drive, Greenwich, Connecticut, U.S.A.	A socio-economic study of arctic problems in terms of environment, resources, utilization, and development. Initiated: 1950—Completion: 1952.

DOROTHY JEAN T. THOMSON, 1603 Tremont Street, Cedar Falls, Iowa, U.S.A.	A study of the social and economic organization in a northern market town (Nome, Alaska) with emphasis on the position of the Eskimo. Initiated: 1950—Completion: Spring 1952.

Geology

EDGAR AUBERT DE LA RUE, 18 Rue Ribera, Paris 16, France.	A study of geology of Ungava Peninsula between Ungava Bay and Hudson Bay. Initiated: 1948—Completion: Spring 1950.
G. DALLAS HANNA, Dept. of Geology, California Academy of Sciences, San Francisco, California, U.S.A.	Investigation of the geology of the continental shelf in the vicinity of Point Barrow, Alaska. Initiated: 1954—Completion: 1956.
E. H. KRANCK, Dept. of Geology, McGill University, Montreal, Quebec, Canada.	Geological study of the east coast of Hudson Bay. Initiated: 1947—Completion: Spring 1949.
JOHN B. LUCKE, Dept. of Geology, University of Connecticut, Storrs, Connecticut, U.S.A.	Geologic investigation of the Shelikof Strait area, Alaska. Initiated: 1953—Completion: 1955.
DONALD G. MACVICAR, JR., Dept. of Geology, Yale University, New Haven, Connecticut, U.S.A.	Detailed field study and mapping of the Pleistocene and bedrock geology of the Chandler Lake area, Brooks Range, Alaska. Initiated: 1955—Completion: 1957.
ANDREW H. MCNAIR AND DONALD B. WALES, Dept. of Geology, Dartmouth College, Hanover, New Hampshire, U.S.A.	A stratigraphic study of the Lower Paleozoic rocks of the south coast of Devon Island, Northwest Territories. Initiated: 1949—Completion: 1951.
WILLIAM QUAIDE, Museum of Paleontology, University of California, Berkeley, California, U.S.A.	An enquiry into the paleontological and geological history of Petroleum Reserve No. 4 and adjoining areas, Point Barrow, Alaska. Initiated: 1953—Completion: 1955.
JOHANNES C. TROELSEN, Universitetets Mineralogiske Museum, Østervoldgade 7, Copenhagen K, Denmark.	A study of Canyon Fiord, Ellesmere Island, with particular reference to the glaciological and geological history of the Franklinian Geosyncline. Initiated: 1952—Completion: 1955.
A. L. WASHBURN, Arctic Institute of North America, 1530 P Street N.W., Washington 5, D.C., U.S.A.	Reconnaissance geology of northern Victoria Island, Northwest Territories. Initiated: 1949—Completion: Spring 1951.

Glaciology

PATRICK D. BAIRD, Arctic Institute of North America, 3485 University Street, Montreal 2, Quebec, Canada.	Glaciological investigations of the Penny Icecap, Baffin Island. Initiated: 1953—Completion: 1955.
RICHARD C. HUBLEY, Dept. of Meteorology and Climatology, University of Washington, Seattle, Washington, U.S.A.	Development and field testing of methods and instruments for accurate measurement of glacier budget, snow ablation, and total radiation balance over a glacier surface. Initiated: 1955—Completion: 1957.
MAYNARD M. MILLER, American Geographical Society, Broadway at 156th Street, New York 32, New York, U.S.A.	A glaciological study of the Juneau Ice Field in southeastern Alaska. Initiated: 1949—Completion: Spring 1950.
MAYNARD M. MILLER, American Geographical Society, Broadway at 156th Street, New York 32, New York, U.S.A.	Glaciological research in Alaska. Initiated: 1952—Completion: 1955.

LAWRENCE E. NIELSEN, Springfield, Massachusetts, U.S.A.	Preliminary glaciological and meteorological study of the Columbia Glacier region of the Chugach Mountains, Alaska. Initiated: 1955—Completion: 1957.
ROBERT P. SHARP, Dept. of Geology, California Institute of Technology, Pasadena, California, U.S.A.	A thorough study of the lower course of the Saskatchewan Glacier. Initiated: 1952—Completion: 1955.
WALTER A. WOOD, Arctic Institute of North America, 2 East 63rd Street, New York 21, New York, U.S.A.	Project "Snow Cornice"—the establishment of a glacial research station on the Seward Ice Field in the area of the Alaska–Yukon boundary. Initiated: 1948—Completion: Continuing Project.

Invertebrate Zoology

MARIE HAMMER, Stødam, Hillerød, Denmark.	Study of the microfauna of arctic shore areas (Coppermine and Hudson Bay). Initiated: 1948—Completion: Spring 1952.
WILLIAM HOVANITZ, Dept. of Biology, University of San Francisco, San Francisco, California, U.S.A.	An analysis of population structure, genes, and hybridization of arctic and subarctic species of *Colias*. Initiated: 1947—Completion: Spring 1949.
HUGH CECIL HUCKETT, Long Island Vegetable Research Farm, Riverhead, New York, U.S.A.	The arctic and subarctic Muscidae of North America. Initiated: 1952—Completion: 1955.
ROMAN KENK, 3350 Blaine Street N.W., Washington, D.C., U.S.A.	An investigation of the ecology and zoogeographical significance of lower freshwater invertebrates, in particular freshwater Triclads (*Turbellaria*) in arctic Alaska. Initiated: 1950—Completion: 1951.
HARRY V. KROGERUS, Mannersheimvagen 25A, Helsinki, Finland.	A faunistic and ecological exploration of the Lepidoptera, Diptera, and Hymenoptera of Newfoundland. Initiated: 1949—Completion: Spring 1952.
CARL H. LINDROTH, Zoological Institute, Lund, Sweden.	A faunistic and ecological exploration of the Coleoptera (especially *Carabidae*) of Newfoundland. Initiated: 1949—Completion: Spring 1953.
RICHARD H. MCBEE, Montana State College, Bozeman, Montana, U.S.A.	A study of thermophilic bacteria in arctic soils and waters in the vicinity of Point Barrow, Alaska. Initiated: 1954—Completion: 1956.
B. ELWOOD MONTGOMERY, Purdue University, Lafayette, Indiana, U.S.A.	Ecology of the insects of the Arctic Slope of Alaska. Initiated: 1955—Completion: 1957.
IRWIN M. NEWELL, Agricultural Experiment Station, University of Hawaii, Honolulu, Hawaii.	A comparative study of mite fauna of the North American Arctic (Barrow and southward). Initiated: 1948—Completion: Spring 1951.
ERNST P. PALMEN, Zoological Institute, University of Helsinki, Helsinki, Finland.	A faunistic and ecological exploration of the Diplopoda, Chilopoda, Isopoda, Terrestria, and in part of the phytophagous Coleoptera (*Chrysomelidae, Curculionidae*) of Newfoundland. Initiated: 1949—Completion: Spring 1952.
EDWARD B. REED, Dept. of Zoology, Colorado A. & M. College, Fort Collins, Colorado, U.S.A.	Investigation of the entomostracan fauna in the lakes and ponds of the Colville and Canning rivers, Alaska. Initiated: 1955—Completion: 1957.

Reese I. Sailer, U.S. National Museum, Washington, D.C., U.S.A.	Correlation of accumulated precipitation data with mosquito abundance in Alaska. Initiated: 1953—Completion: 1955.
Neal A. Weber, c/o U.S. Information Service, Baghdad, Iraq.	An entomological survey of the Arctic Slope of Alaska. Initiated: 1949—Completion: 1950.

Mammalogy

G. C. L. Bertram, Scott Polar Research Institute, Cambridge, England.	A study of the fur seals of the Pribilof Islands (Alaska) with special reference to the behaviour and methods of age determination of seals and the utilization of the carcasses. Initiated: 1949—Completion: Spring 1952.
Francis H. Fay, Dept. of Zoology, University of British Columbia, Vancouver, British Columbia, Canada.	The life history of the Pacific walrus. Initiated: 1952—Completion: 1955.
Francis H. Fay, Dept. of Zoology, University of British Columbia, Vancouver, British Columbia, Canada.	Continuation of a study of the life history of the Pacific walrus. Initiated: 1953—Completion: 1955.
Herbert C. Hanson, Dept. of Biology, Catholic University of America, Washington 17, D.C., U.S.A.	A study of the phytogeography, location, and condition of reindeer range and of the management of reindeer in western Alaska. Initiated: 1950—Completion: Spring 1952.
Per Host, Norsk Kulturfilm, Solplassen 1, Oslo, Norway.	A study of the hooded seals in the Newfoundland–Labrador–Greenland region. Initiated: 1950—Completion: Spring 1952.
William V. Mayer, Dept. of Zoology, University of Southern California, Los Angeles, California, U.S.A.	The life history of the arctic ground squirrel (*Citellus Parryii*). Initiated: 1953—Completion: 1955.
George Athan Petrides, Michigan State College, Lansing, Michigan, U.S.A.	An exploratory study of the feasibility of determining annual survival and mortality rates for young of the year and for adults in important fur species at various times in the cycle. Initiated: 1951—Completion: 1953.
Frank A. Pitelka, Museum of Vertebrate Zoology, University of California, Berkeley, California, U.S.A.	Population biology of arctic land vertebrates. Initiated: 1953—Completion: 1955.
Frank A. Pitelka, Museum of Vertebrate Zoology, University of California, Berkeley, California, U.S.A.	A study of problems in lemming ecology based on recent work near Point Barrow, Alaska. Initiated: 1955—Completion: 1957.
Horace F. Quick, School of Forestry, University of Michigan, Ann Arbor, Michigan, U.S.A.	A study of the habits and economics of fur animals as factors of management and conservation. Initiated: 1947—Completion: Spring 1950.
A. L. Rand, Chicago Natural History Museum, Chicago 5, Illinois, U.S.A.	A study of the mammal population of the Canadian Arctic north of latitude 60° and its value for survival. Initiated: 1947—Completion: Spring 1949.
Robert F. Scott, Wildlife Management, Anchorage, Alaska.	An aerial survey of Dall sheep in Alaska to determine limits of range, and present distribution and abundance. Initiated: 1950—Completion: Spring 1952.

BERNARD J. SULLIVAN, Biology Dept., Boston College, Chestnut Hill 67, Massachusetts, U.S.A.
A biochemical and histochemical analysis of the tissues of certain arctic animals to determine the amount and localization of lipids, glucose, and glycogen.
Initiated: 1950—Completion: 1952.

D. Q. THOMPSON, Dept. of Zoology, University of Missouri, Columbia, Missouri, U.S.A.
To continue the broad studies begun in 1950 on the periodic fluctuations in animal populations and specifically of the lemmings (*Lemmus* and *Dicrostonyx*).
Initiated: 1953—Completion: 1955.

D. Q. THOMPSON, Dept. of Zoology, University of Missouri, Columbia, Missouri, U.S.A.
A continued study of the ecology of the lemmings in the vicinity of Point Barrow, Alaska.
Initiated: 1954—Completion: 1956.

CHARLES G. WILBER, Biological Laboratories, St. Louis University, St. Louis, Missouri, U.S.A.
A study of the biochemical characteristics of arctic animals.
Initiated: 1950—Completion: 1951.

Marine Biology

ADAM BURSA, 548 West 113 St., New York City, New York, U.S.A.
Studies of the annual cycle of phytoplankton production in the Arctic Ocean.
Initiated: 1954—Completion: 1956.

PAUL AUGUSTUS DEHNEL, Dept. of Zoology, University of California, Los Angeles, California, U.S.A.
Growth rates of marine invertebrates as a function of latitude.
Initiated: 1952—Completion: 1955.

PAUL AUGUSTUS DEHNEL, Dept. of Zoology, University of California, Los Angeles, California, U.S.A.
The general problem of productivity of organic matter in the sea, with particular reference to the waters in the vicinity of Mt. Edgecombe, Alaska.
Initiated: 1954—Completion: 1956.

D. V. ELLIS, Dept. of Zoology, McGill University, Montreal, Quebec, Canada.
Distribution and ecology of the littoral and shallow water fauna and flora of the Canadian Arctic.
Initiated: 1954—Completion: 1956.

D. V. ELLIS, Dept. of Zoology, McGill University, Montreal, Quebec, Canada.
A continuation of studies of the distribution and ecology of the littoral and shallow water fauna and flora of the Canadian Arctic.
Initiated: 1955—Completion: 1957.

MRS. GEORGE E. MACGINITIE, The Kerckhoff Marine Laboratory, California Institute of Technology, Corona Del Mar, California, U.S.A.
To make final checks at the U.S. National Museum, Washington, D.C., for a paper on the molluscs of Point Barrow, Alaska.
Initiated: 1955—Completion: 1956.

W. D. MATEER, Colorado School of Mines, Golden, Colorado, U.S.A.
Ecology of the arctic Foraminifera in the vicinity of Point Barrow, Alaska.
Initiated: 1953—Completion: 1955.

JOHN LUTHER MOHR, Dept. of Zoology, University of Southern California, Los Angeles, California, U.S.A.
Investigations of some aspects of the ecology of arctic crustaceans.
Initiated: 1953—Completion: 1955.

JOHN LUTHER MOHR, Dept. of Zoology, University of Southern California, Los Angeles, California, U.S.A.
Continued investigation of the ecology of arctic crustaceans with emphasis on the interrelations with the fish population.
Initiated: 1954—Completion: 1956.

DAVID C. NUTT, Dartmouth College Museum, Hanover, New Hampshire, U.S.A.
Hydrobiological study in the coastal waters of Labrador.
Initiated: 1954—Completion: 1956.

PER FREDERICK SCHOLANDER, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.
An investigation of osmotic pressures in the blood of arctic and subarctic marine fishes.
Initiated: 1953—Completion: 1955.

PER FREDERICK SCHOLANDER, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.	Expansion of investigations of osmotic pressures in the blood of arctic and subarctic marine fishes. Initiated: 1954—Completion: 1956.
PER F. SCHOLANDER, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.	Winter investigations of osmotic pressures in the blood of certain arctic and subarctic marine fishes in the vicinity of Hebron Fiord, Labrador. Initiated: 1955—Completion: 1957.
ROBERT THAYER WILCE, Dept. of Botany, University of Michigan, Ann Arbor, Michigan, U.S.A.	The marine flora in the Strait of Belle Isle, Newfoundland. Initiated: 1954—Completion: 1956.
ROBERT W. WILCE, Dept. of Botany, University of Michigan, Ann Arbor, Michigan, U.S.A.	Studies of the marine flora of Ungava Bay and northwest Labrador. Initiated: 1955—Completion: 1957.
NORMAN J. WILIMOVSKY, Natural History Museum, Stanford University, Stanford, California, U.S.A.	A survey of the fishes of arctic Alaska with particular reference to those of importance to the military and naval services. Initiated: 1954—Completion: 1956.
NORMAN J. WILIMOVSKY, Dept. of Zoology, Natural History Museum, Stanford University, Stanford, California, U.S.A.	Continuation of the survey of the fishes of arctic Alaska, with particular reference to those of importance to the military and naval services. Initiated: 1955—Completion: 1957.
DONALD E. WOHLSCHLAG, Natural History Museum, Stanford University, Stanford, California, U.S.A.	The usefulness of fishery resources and the determination of the nature and extent of fish stocks of individual species in the waters of arctic Alaska on morphological, ecological, and physiological bases. Initiated: 1954—Completion: 1956.

Oceanography

M. J. DUNBAR, Dept. of Zoology, McGill University, Montreal, Quebec, Canada.	A study of the oceanography of the Canadian Eastern Arctic. Initiated: 1947—Completion: Spring 1949.
ROBERT L. EDWARDS, 46 Lincoln Street, Waltham, Massachusetts, U.S.A.	Hydrographic and ecological studies of four representative marine areas in James Bay and Hudson Bay. Analysis of water exchange between Richmond Gulf and Hudson Bay. Initiated: 1954—Completion: 1956.
DAVID C. NUTT, Dartmouth College Museum, Hanover, New Hampshire, U.S.A.	A cooperative study of certain aspects of the oceanography and hydrography of the coastal waters of western Newfoundland and southern Labrador. Initiated: 1949, 1950, 1951, 1952—Completion: 1955.
DAVID C. NUTT, Dartmouth College Museum, Hanover, New Hampshire, U.S.A.	Winter oceanographic studies of southern Labrador. Initiated: 1953—Completion: 1955.
NORMAN J. WILIMOVSKY, Natural History Museum, Stanford University, Stanford, California, U.S.A.	The determination of the relative nutriment content of ice-melt waters in the vicinity of Point Barrow, Alaska, and a comparison with similar factors in neighbouring open seas. Initiated: 1954—Completion: 1956.

Ornithology

PAUL H. BALDWIN, Dept. of Zoology, Colorado A. & M. College, Fort Collins, Colorado, U.S.A.	The breeding, ecology, and physiological rhythms of some arctic birds at Umiat, Alaska. Initiated: 1953—Completion: 1955.

Irven O. Buss, Wildlife Management, State College of Washington, Pullman, Washington, U.S.A.	Studies of territory, breeding, behaviour, range requirements (loafing, feeding, nesting), and breeding density of the Upland Plover at the northern extremity of its range in Yukon Territory. Initiated: 1950—Completion: Spring 1952.
T. J. Cade, University of Alaska, College, Alaska.	A complete survey of the avifauna of St. Lawrence Island, Alaska, particularly to study the feeding and nesting habits, and the ecological associations of the various species. Initiated: 1950—Completion: Spring 1951.
Frederick Graham Cooch, Dept. of Conservation, Cornell University, Ithaca, New York, U.S.A.	The Blue Goose: life history, ecology, and management. Initiated: 1952—Completion: 1955.
Carl R. Eklund, Ft. Washington, Maryland, U.S.A.	Waterfowl nesting survey of Ungava Peninsula with particular reference to the Black Duck. Initiated: 1949—Completion: Spring 1952.
Harold C. Hanson, Illinois Natural History Survey, Urbana, Illinois, U.S.A.	A study of the breeding habits of the Canada Goose on the west coast of James Bay. Initiated: 1946—Completion: 1949.
E. O. Höhn, University of Alberta, Edmonton, Alberta, Canada.	Ornithological field work with collecting and banding in the vicinity of Anderson River to Paulatuk, District of Mackenzie, Northwest Territories. Initiated: 1955—Completion: 1957.
Phillip S. Humphrey, University of Michigan, Museum of Zoology, Ann Arbor, Michigan, U.S.A.	Summer behaviour and ecology of certain sea ducks. Initiated: 1952—Completion: 1955.
Henry C. Kyllingstad, 1419 Santa Cruz Drive, Santa Fe, New Mexico, U.S.A.	A study of certain ornithological problems in the Norton Sound region of Alaska. Initiated: 1948—Completion: 1952.
Paul Queneau, Peter M. Scott, Harold C. Hanson, c/o Paul Queneau, 1 St. John Place, Westport, Connecticut, U.S.A.	A waterfowl survey of the Perry River area northern Canada. Initiated: 1949—Completion: 1952.
George M. Sutton, Dept. of Zoology, University of Oklahoma, Norman, Oklahoma, U.S.A.	A comprehensive study of the birds of the holarctic region. Initiated: 1953—Completion: 1955.
V. C. Wynne-Edwards, Dept. of Natural History, Aberdeen University, Aberdeen, Scotland.	A study of the distribution and breeding biology of the sea birds of southern Baffin Island. Initiated: 1953—Completion: 1955.

Permafrost

R. A. Hemstock, Devon, Alberta, Canada.	To gather and compile all available data on permafrost in the Norman Wells area and to continue a study of permafrost and related soil and snow mechanics with a view to improving the present methods of road building, communications, and general construction in the arctic and subarctic regions. Initiated: 1947—Completion: Spring 1949.

General

Patrick D. Baird, Arctic Institute of North America, 3485 University Street, Montreal 2, Quebec, Canada.	A glaciological, geological, and biological investigation of the River Clyde region, northeastern Baffin Island. Initiated: 1950—Completion: Spring 1952.

DONALD J. BELCHER, School of Civil Engineering, Cornell University, Ithaca, New York, U.S.A.	The use of aerial photographs for predetermining ground conditions influencing engineering structures and construction practices in the arctic and subarctic regions of North America. Initiated: 1947—Completion: Spring 1949.
MALCOLM BROWN, Kingston General Hospital, Kingston, Ontario, Canada.	A study of the peripheral circulation in acclimatized Eskimo subjects on Southampton Island, Northwest Territories. Initiated: 1949—Completion: Spring 1952.
JOHN D. CAMPBELL, Dept. of Botany, McGill University, Montreal, Quebec, Canada.	A paleobotanical-stratigraphical study of the "Muck" deposits of the Klondike district, Yukon Territory, with the view to collecting evidence on glacial and postglacial climatic sequences. Initiated: 1951—Completion: Spring 1953.
J. LOCKWOOD CHAMBERLIN, West Chester, Pennsylvania, U.S.A.	Winter investigations of the marine biology and hydrography of eastern coastal waters of James and Hudson bays. Initiated: 1955—Completion: 1957.
LYMAN J. CHAPMAN, Ontario Research Foundation, 43 Queen's Park, Toronto, Ontario, Canada.	Evapotranspiration studies in northern Canada. Initiated: 1953—Completion: 1955.
C. T. ELVEY, Geophysical Institute, College, Alaska.	Studies of the absorption in the ionosphere of earth currents, and of magnetic disturbances, auroral displays, and problems of radio propagation at Point Barrow, Alaska. Initiated: 1955—Completion: 1957.
DAVID B. ERICSON, Lamont Geological Observatory, Columbia University, Palisades, New York, U.S.A.	Micropaleontological, petrographic, and chemical examination of sediment cores from arctic and subarctic waters as factors reflecting climatic shifts, ocean current circulation, and glaciology. Initiated: 1954—Completion: 1956.
MARJORIE CRAVEN FINDLAY, 25 Gainsford Road, Worthing, Sussex, England.	Adoption of sheep farming by Greenlandic seal hunters. Initiated: 1952—Completion: 1953.
KAREN J. FRIEDMAN, U.S. Dept. of Agriculture, Washington, D.C., U.S.A.	Current transition in Greenland's economy. Initiated: 1953—Completion: 1955.
MALCOLM S. GORDON, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.	Studies of the blood plasma and muscle in arctic char. Initiated: 1955—Completion: 1957.
TREVOR LLOYD, Dept. of Geography, Dartmouth College, Hanover, New Hampshire, U.S.A.	A study of arctic and associated matters in the United Kingdom, Denmark, Norway, Sweden and Finland. Initiated: 1949—Completion: 1952.
ROSARIO MAZZEO, Massachusetts Audubon Society, Boston, Massachusetts, U.S.A.	A study of the ornithology, botany, geology, and geomorphology of certain parts of Bylot Island. Initiated: 1954—Completion: 1956.
XAVIER J. MUSACCHIA, Dept. of Biology, St. Louis University, St. Louis, Missouri, U.S.A.	A study of the carbohydrates and lipids of the invertebrates and vertebrates of the Point Barrow region, Alaska. Initiated: 1949, 1950—Completion: Autumn 1952.
ROLAND M. NARDONE, Biology Dept., Catholic University of America, Washington 17, D.C., U.S.A.	A study on the environment characteristics and tissue chemistry of the arctic black fish in the vicinity of Point Barrow, Alaska. Initiated: 1955—Completion: 1957.
H. M. RAUP (Cooperative project with FREDERICK JOHNSON), Harvard Forest, Harvard University, Petersham, Massachusetts, U.S.A.	Cooperative study to determine the development sequence in human culture, vegetation, etc. in Yukon Territory. Initiated: 1948—Completion: Spring 1952.

ROGER REVELLE, Scripps Institution of Oceanography, La Jolla, California, U.S.A.	A geologic study of the sea valley–submarine canyon system of Point Barrow, Alaska, and installation of tide gauges. Initiated: 1955—Completion: 1957.
ROBERT W. REX, Scripps Institution of Oceanography, La Jolla, California, U.S.A.	Oceanographic and limnological investigations at Point Barrow, Alaska. Initiated: 1954—Completion: 1956.
MARIE SANDERSON, Ontario Research Foundation, 43 Queen's Park, Toronto, Ontario, Canada.	The establishment of an evapotranspirometer at Norman Wells, Northwest Territories, with a view to obtaining information on water surplus and water deficiencies in northern latitudes and their influence on ground conditions. Initiated: 1949—Completion: 1950.
JOHN C. F. TEDROW, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey, U.S.A.	A pedologic study of the soil-forming processes of the arctic coastal plain of Alaska. Initiated: 1955—Completion: 1957.
ROBERT L. USINGER, University of California, Berkeley, California, U.S.A.	Reconnaissance study of amber deposits in the general vicinity of Point Barrow, Alaska. Initiated: 1955—Completion: 1957.

LIBRARY PROJECTS SPONSORED BY THE ARCTIC INSTITUTE OF NORTH AMERICA

Arctic Institute of North America, Project Director: DUDLEY SMITH.	Compilation of a roster of arctic specialists. Initiated: 1947—Completion: 1950.
Arctic Institute of North America, Project Director: MARIE TREMAINE.	Compilation of a comprehensive annotated bibliography on the Arctic. Initiated: 1947—Completion: Continuing project. First three volumes published summer 1953, by the U.S. Government Printing Office. Volume Four published August 1954. Volume Five published April 1955. Additional volumes in preparation.

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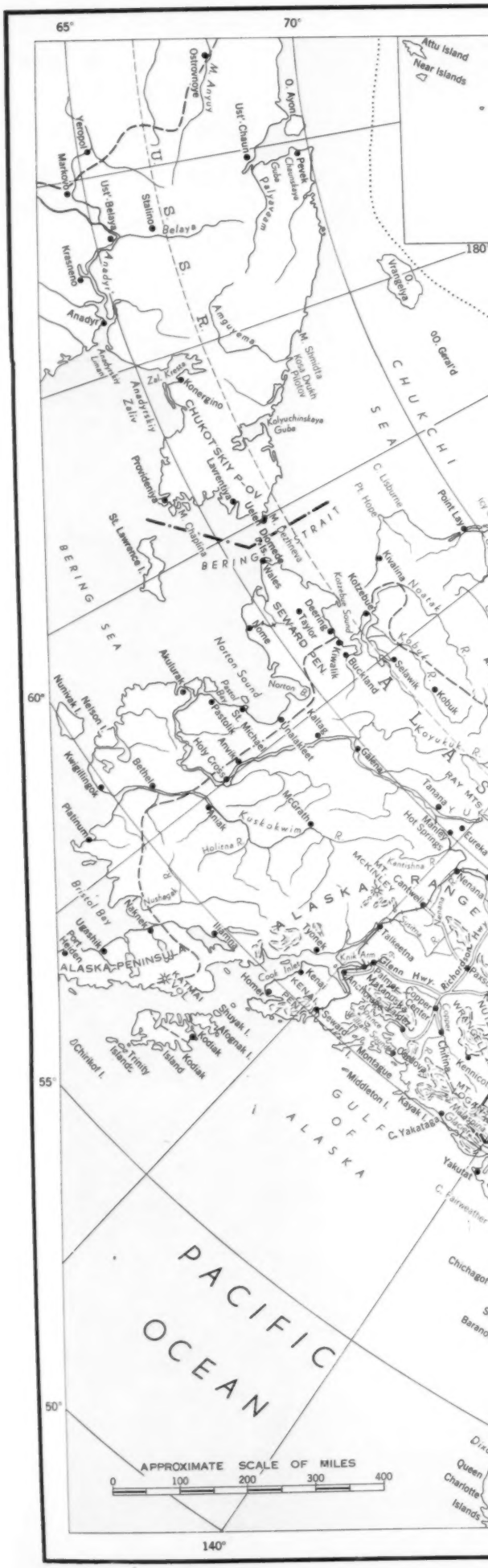
Indexed in the Canadian Index

Authorized as Second Class Mail, Post Office Department, Ottawa

PRINTED IN CANADA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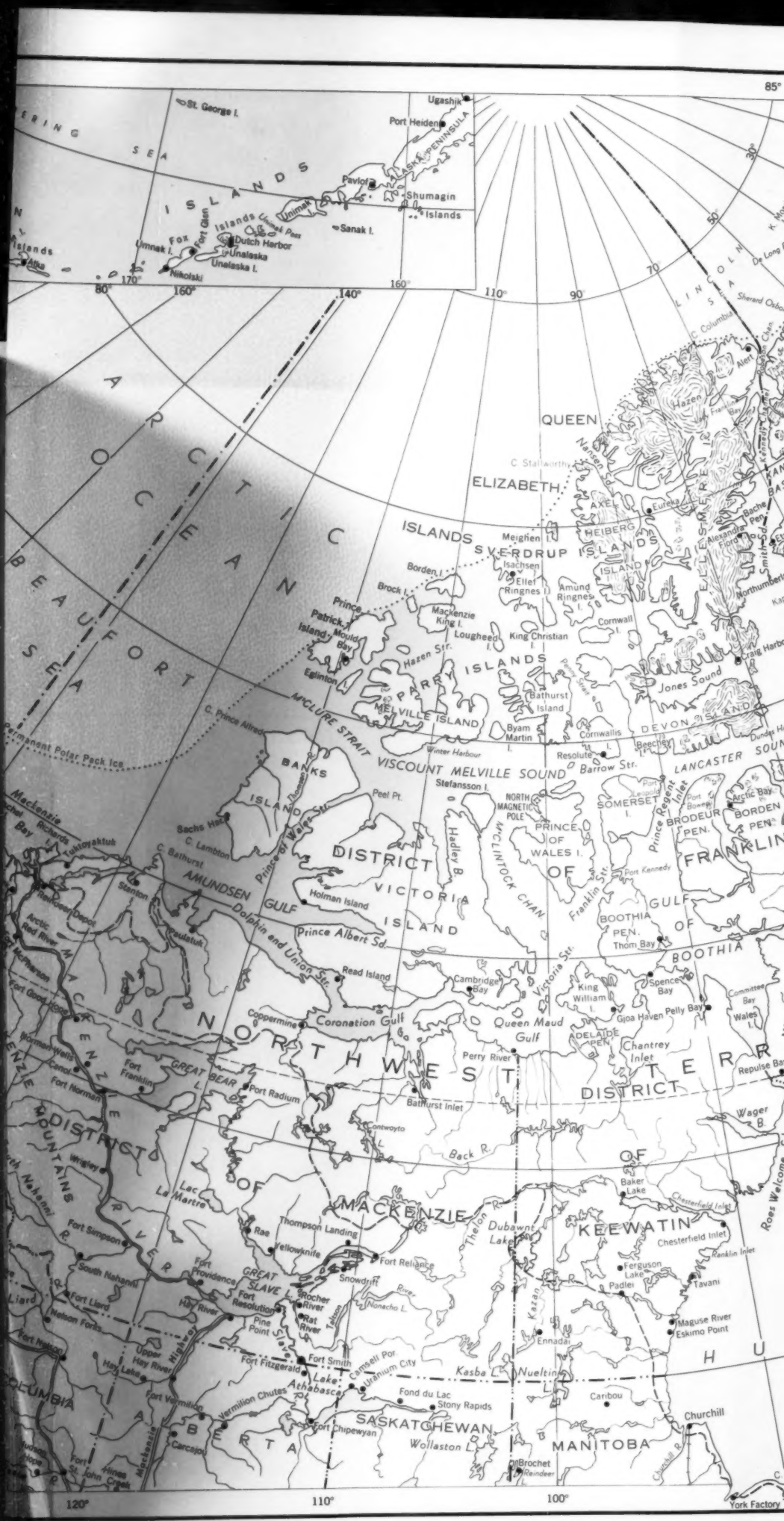
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Unimak Pass
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170°
160°
140°
110°
90°
70°
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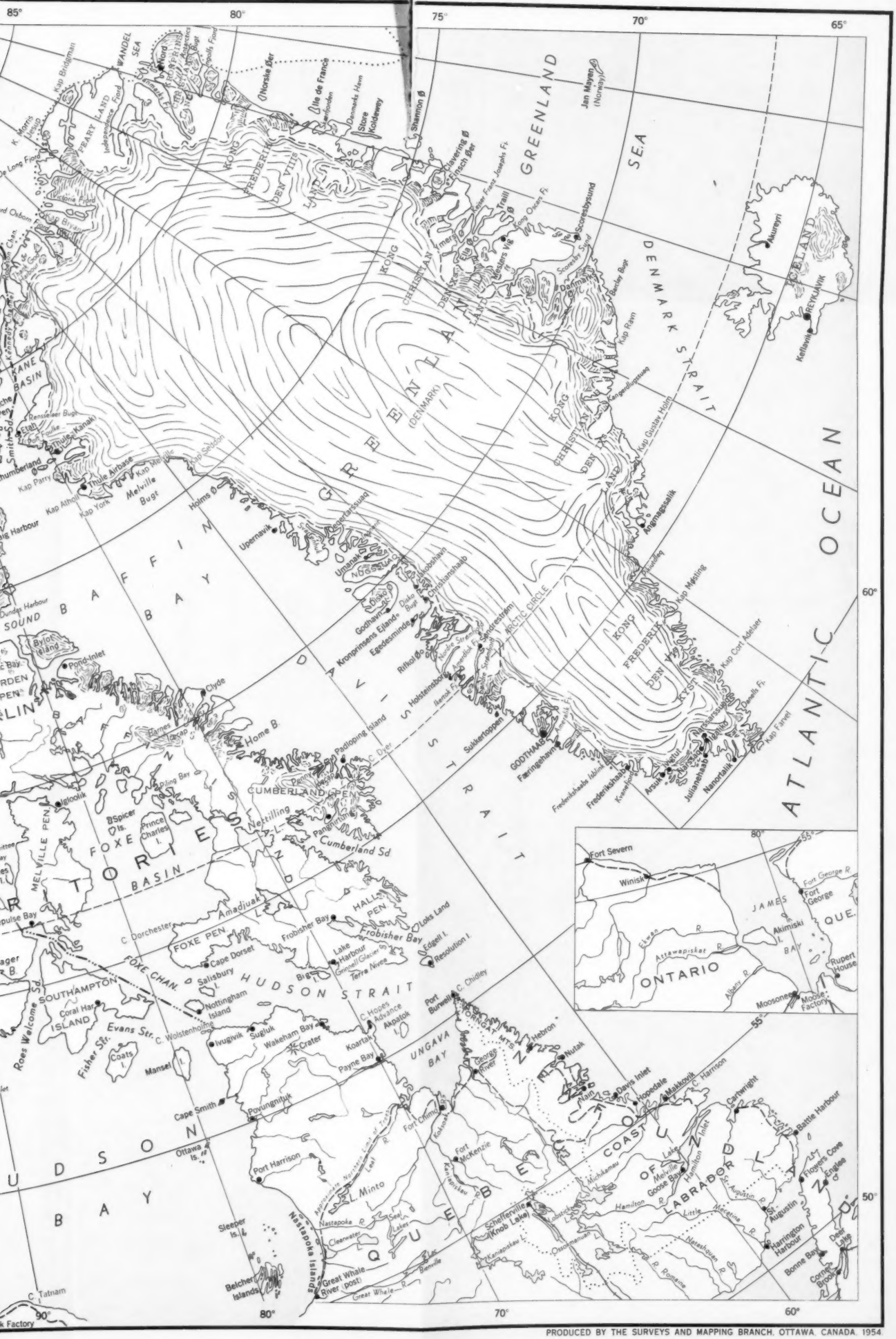
Craig Harbor
Eglinton
PARRY ISLANDS
Jones Sound
Bathurst Island
MELVILLE ISLAND
DEVON ISLAND
Byam Martin I.
Cornwallis
Resolute
Beechey I.
C. Prince Alfred
McCLURE STRAIT
VISCOUNT MELVILLE SOUND
Barrow Str.
LANCASTER SOUND
Winter Harbour
BANKS ISLAND
Stefansson I.
Peel Pt.
NORTH MAGNETIC POLE
SOMERSET I.
Port Leopold
Port Bowen
Arctic Bay
BORDEN PEN.
Mackenzie
Richards Bay
Sachs Harbour
C. Lambton
C. Bathurst
Prince of Wales Str.
Hadley B.
McCLINTOCK CHAN.
PRINCE OF WALES I.
Prince Regent Inlet
BRODEUR PEN.
FRANKLIN
DISTRICT OF VICTORIA ISLAND
AMUNDSEN GULF
Holman Island
Franklin Str.
Port Kennedy
GULF OF BOOTHIA
BOOTHIA PEN.
Thom Bay
Tuktoyaktuk
Reindeer Depot
Arctic Red River
Stanton
Paulatuk
Dolphin and Union Str.
Prince Albert Sd.
Read Island
Cambridge Bay
Victoria Str.
King William I.
Spence Bay
Gjoa Haven
Pelly Bay
Committee Bay
Wales I.
Fort McPherson
Fort Good Hope
Coppermine
Coronation Gulf
Queen Maud Gulf
ADELAIDE PEN.
Chantrey Inlet
Repulse Bay
Norman Wells
Fort Norman
Fort Franklin
GREAT BEAR L.
Port Radium
Perry River
Bathurst Inlet
NORTHWEST TERRITORIES
MACKENZIE MOUNTAINS
Wrigley
Contwoyto L.
Back R.
Wager B.
Lac La Martre
DISTRICT OF MACKENZIE
Baker Lake
Chesterfield Inlet
Rae
Thompson Landing
Yellowknife
Fort Reliance
Thelon R.
Dubawnt Lake
KEEWATIN
Ferguson Lake
Padlei
Tavani
Fort Simpson
South Nahanni R.
Fort Providence
GREAT SLAVE L.
Snowdrift
Kazan R.
Maguse River
Eskimo Point
Fort Liard
Hay River
Fort Resolution
Rocher River
Rat River
Nonacho L.
Ennadai
Nelson Forks
Pine Point
Fort Nelson
Fort Fitzgerald
Fort Smith
Camsell Por.
Uranium City
Kasba L.
Nueltin L.
Upper Hay Lakes
Lake Athabasca
Fond du Lac
Stony Rapids
Caribou
Churchill
Fort Vermilion
Vermilion Chutes
Fort Chipewyan
SASKATCHEWAN
MANITOBA
Wollaston L.
Brochet
Reindeer
Carcajou
Fort St. John
Hines Creek
120°
110°
100°
York Factory


GREENLAND (DENMARK)
BAFFIN ISLAND
DAVIS STRAIT
BAFFIN BAY
HUDSON STRAIT
HUDSON BAY
FOXE BASIN
FOXE CHAN.
FOXE PEN.
HALL PEN.
CUMBERLAND PEN.
MELVILLE PEN.
SOUTHAMPTON ISLAND
BAFFIN LAND
PRINCE CHARLES I.
AKPATOK I.
NOTTINGHAM ISLAND
COATS I.
MANSEL I.
SLEEPER IS.
OTTAWA IS.
BELCHER ISLANDS
RESOLUTION I.
EDGELL I.
LOKS LAND
SPICER IS.
KANE BASIN
WANDEL SEA
GREENLAND SEA
DENMARK STRAIT
ATLANTIC OCEAN
ICELAND
UNGAVA BAY
LABRADOR
QUEBEC
ONTARIO
JAMES BAY
Thule Airbase
Thule
Pond Inlet
Clyde
Igloolik
Cape Dorset
Frobisher Bay
Lake Harbour
Cape Smith
Povungnituk
Port Harrison
Great Whale River (post)
Nastapoka Islands
Fort McKenzie
Fort Chimo
Port Burwell
Hebron
Nutak
Nain
Davis Inlet
Hopedale
Makkovik
Cartwright
Battle Harbour
Flowers Cove
Englee
St. Augustin
Harrington Harbour
Bonne Bay
Deer Lake
Corner Brook
Fort Severn
Winisk
Fort George
Akimiski I.
Rupert House
Moosonee
Moose Factory
Godthaab
Christianshaab
Holsteinsborg
Sukkertoppen
GODTHAAB
Færingehavn
Frederikshaab
Julianehaab
Nanortalik
Kap Farvel
Upernavik
Umanak
Holms Ø
Jan Mayen (Norway)
Akureyri
Reykjavik
Kap Bridgman
Kap Morris Jesup
Kap Parry
Kap Athol
Kap York
Kap Melville
Kap Sabine
Melville Bugt
Kap Alexander
Kap Ravn
Kap Gustav Holm
Kap Mösting
Kap Cort Adelaer
Kap Desolation
Kap Dan
Kap Farvel
Scoresbysund
Ile de France
Norske Øer
Shannon Ø
Danmarks Havn
Store Koldewey
Pond Inlet
Byam Martin I.
Padloping Island
Home B.
Nettilling L.
Amadjuak L.
Big I.
Koartak
Payne Bay
Wakeham Bay
Sugluk
Ivugivik
Salisbury
Nottingham Island
Coral Harbour
Evans Str.
Fisher Str.
Ross Welcome Sd.
Melville Bugt
Dundas Harbour
Craig Harbour
Cape Sabine
Cape Parry
Cape Athol
Cape York
Cape Melville
Cape Sabine
Cape Alexander
Cape Dyer
Cape Dorchester
Cape Wolstenholme
Cape Tatnam
Cape Chidley
Cape Harrison
Cape Porcupine
Cape Harrison
Cape Wolstenholme
Cape Tatnam
Lake Harbour
Grinnell Glacier
Terra Nova
Big I.
Koartak
Payne Bay
Crater
Amadjuak L.
Nettilling L.
Padloping Island
Home B.
Pond Inlet
Byam Martin I.
Clyde
Igloolik
Spicer Is.
Prince Charles I.
Cumberland Sd.
Frobisher Bay
Lake Harbour
Cape Dorset
Salisbury
Nottingham Island
Coral Harbour
Evans Str.
Fisher Str.
Ross Welcome Sd.
Coats I.
Mansel I.
Sleeper Is.
Ottawa Is.
Belcher Islands
Great Whale River (post)
Nastapoka Islands
Port Harrison
Povungnituk
Cape Smith
Ivugivik
Sugluk
Wakeham Bay